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Newton Lacy Pierce
1905-1950

By LYMAN SPITZER, JR.

With the death on August 9, 1950, of Newton Lacy Pierce accurate observational astronomy has lost one of its most earnest devotees. His passion for precision and scrupulous attention to detail made him a worthy successor to the late Raymond S. Dugan, and his passing will be mourned by his many friends and colleagues.

He was born on July 12, 1905, in Santa Ana, California. His maternal grandfather, who had crossed the continent in a covered wagon some decades earlier, was a physician. Pierce's own father, a graduate from the University of Michigan, was an expert in plant diseases with the U. S. Department of Agriculture, and his meticulously careful drawings of plant and insect life helped give his son a thorough respect for careful and accurate work. Like his father, New-

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ton Pierce went as an undergraduate to Michigan where he became a member of Sigma Xi and received his B.S. in February, 1928. While at Michigan, he studied under the late Ralph H. Curtiss, who stimulated his interest in astronomy and encouraged him to seek his career in this subject; Curtiss even gave his own weekly night at the 36-inch telescope to Pierce for observational research as an undergraduate.

Immediately after he had received his B.S., Pierce started work for his master's degree. Financial problems made this road a long one, and it is a tribute to his perseverance and singleness of purpose that he did not abandon his goal. After a few months at Michigan, he left for Crete, Nebraska, where he taught astronomy at Doane College during 1928-29. The following year he was offered an instructorship at Northwestern University, a position which he held for the next six years, working at Michigan every summer on his master's degree, which he received in 1934. During this period his major effort was on the Eros campaign; he and Oliver J. Lee jointly took the plates in 1931, and Pierce did most of the work in the reduction of the measurements. This work was by no means his only interest, however. The problems on which he collaborated with others include such topics as spectral classification, determination of absolute magnitudes, and precise measurement of longitude. He was sole author of a paper on the visual spectrum of Nova Herculis 1934.

On June 15, 1935, he married Miss Beatrice Rieke, a graduate of Northwestern University. Their marriage was a very happy one and the Pierces seemed inseparable. They had no children.

In the fall of 1935 he came to Princeton University as a candidate for the Ph.D. degree. Dugan had already begun to suffer from arthritis, and came to rely increasingly on Pierce for work at the 23-inch telescope, newly mounted in 1932. The older man exerted a strong influence on the younger; the two were remarkably similar in scientific outlook. Pierce obtained his Ph.D. degree in 1937, with an observational thesis on the eclipsing variables SV Cam, XX Cas, and RW CBr. The measurements were obtained visually with a polarizing photometer, in the best Dugan tradition of thorough accuracy.

During the remaining thirteen years until his death, Pierce remained at Princeton, first as an assistant, but with promotions every two or three years; in 1938 he became a research associate, in 1940 an instructor, in 1943 an assistant professor, and, in 1946, an associate professor. In the few years before the war he published several more papers on eclipsing variables, but the war, with its heavy teaching load in navigation, took him away from research almost entirely. During this period he collaborated with John Q. Stewart on a successful textbook, "Marine and Air Navigation," the first presentation of these two topics on a unified basis.

After the war Pierce returned to the eclipsing variable field with more ambitious goals in mind. Convinced that the visual photometer was obsolete, he resolved to build a photoelectric photometer that would yield the highest possible accuracy consistent with the Princeton sky. To reduce as far as possible the errors introduced by a time variation of atmospheric transmission he planned a dual-head photometer, to make simultaneous measurements on both the variable and the comparison stars. To measure the outputs from the photocells, electron-count-

ing circuits were planned, instead of the more usual galvanometers, partly because of the greater accuracy of pulse-counting techniques and partly because of their greater adaptability to automatic digital recording. With the automatic features planned, it was expected that the rapid rate at which precise observations could be made would largely offset the geographical disadvantage imposed by Princeton's climate and the few nights of clear sky. The photometer, built in collaboration with William Blitzstein, was largely complete, except for certain automatic features, and would have been in operation on the telescope within a few months.

Despite the heavy burden of work in the field of electronics, a subject hitherto completely unfamiliar to him, Pierce yet found time for much other work. He maintained a complete catalogue of literature on eclipsing stars, and, in 1947, issued a revised Finding List of these objects, a most useful volume to all workers in this field. He took his teaching duties most conscientiously, and spent long hours with individual students, showing them how to make observations and imparting to them something of his own love for precision and careful measurement. He took an active interest in the work of the I.A.U. Commission 27 on Variable Stars, of which he was a member. He participated actively in the administration of the department, and handled much of the detailed work needed in this connection, serving virtually as an assistant director. Perhaps this heavy burden of work and his habitually late hours at his office contributed to his unexpected death from a cerebral hemorrhage in the early morning of August 9. He is survived by his wife and his mother, Mrs. Maude Pierce of Santa Ana.

Behind him Newton Pierce leaves a devoted circle of friends and students. His quiet humor, his patience, his interest in people, his infectious smile,—these and many other likeable personal qualities have endeared him to those that knew him. Those who worked under him or with him could not but help acquiring some of his own eagerness for precision in every detail of astronomical observation. Observers such as he have provided the solid stone with which the soaring tower of modern astronomy has been reared.

In accordance with suggestions from several of his friends, it is proposed if contributions permit to set up a special fellowship fund as a memorial to Newton Pierce. It is planned to combine such a fund with the existing Thaw Fellowship fund of Princeton University, and to support able young graduate students in astronomy with Thaw-Pierce Fellowships from this joint fund.

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The Discovery and Exploitation of Spectroscopic Parallaxes*†

By DORRIT HOFFLEIT

While the major features of stellar spectra are correlated with the temperatures of the stars, it is well known that the relative intensities of some of the lines depend upon the pressure in the stellar atmospheres. Since the pressures determine the luminosities, measurements of the intensities of particular pressure-sensitive lines are calibrated directly in terms of absolute magnitude. Parallaxes are then computed from the familiar relation,

$$\log \pi = 0.2\,(M - m) - 1. \qquad (1)$$

Thus the term "spectroscopic parallax" is really somewhat of a misnomer, the parallax being simply a secondary product of the absolute-magnitude determination. The method, however, has wide application. Relation (1) holds for stars of any apparent magnitude, m, provided only that the apparent magnitudes are inappreciably affected by interstellar absorption. Hence the only obvious limitation to the application of the method has generally been assumed to be the limiting magnitude to which spectra of sufficient resolving power can be obtained. In other words, the accuracy of the method should not depend on the actual distance of the star, except insofar as interstellar absorption plays an adverse role. The parallax being simply the secondary derived result, the history developed here will deal primarily with the determinations of stellar absolute luminosities from spectral characteristics.

How was the spectroscopic parallax method discovered? Was it a happy chance-discovery, or the consequence of formal logic and planned search for luminosity criteria? Both elements played their rôles. A dozen years ago it appeared as if the method was well established for most stars of spectral classes A5 through M. The major question in the minds of many astronomers at that time concerned the limiting sensitivity of the method for determining the true dispersion of absolute magnitudes along each of the two major sequences. For example, when the latest Mount Wilson Catalogue of Spectroscopic Absolute Magnitudes and Parallaxes (*Ap. J.*, **81**, 187; *Mt. W. Contr.* 511) appeared in 1935, no one doubted that, by and large, the stars of a given spectral sub-division on the main sequence that had been assigned absolute magnitudes slightly brighter than the average were in fact intrinsically somewhat the brighter. But whether the true spread in each of the major sequences was equal to or greater than that implied by the pub-

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†This paper is a part of the investigations of stellar absolute magnitudes and parallaxes in which the author is being aided by a contract with the Office of Naval Research.

lished results was a matter of wide concern. Both van Rhijn (*G.P.*, **49**, 1939) and Russell and Moore (*Ap. J.*, **92**, 297; *Mt. W. Contr.* 636) analysed the results extensively and both reached the conclusion that the spread of the absolute magnitudes should be of the order of 40 per cent greater than the indicated spread. The arguments seemed convincing. Yet, more recently, skeptics have arisen who ask, is the heretofore established method really worth while? Is not the dispersion of the absolute magnitudes of stars along the main sequence, for example, merely the consequence of the natural uncertainties of the estimates? If we subclassify the spectra accurately, taking peculiarities into account, will we not succeed in separating all stars into a relatively few discrete sequences? Then a simple listing of only two parameters, say, spectral class and some other discriminant like Morgan's Luminosity Class, will automatically define the absolute magnitude. Thus, would not one critical glance at a spectrum yield results as accurate as the laborious estimates of line-intensities and the cumbersome calibration procedures of the past? In this development of the history of spectroscopic parallaxes we shall attempt to weigh the evidence for both points of view.

Historic Forerunners

Fraunhofer, the first to turn a simple spectroscope to the stars, noted in 1817 that stellar spectra are not all alike. In 1815 he had counted some 576 lines in the solar spectrum and mapped 324 of them. Were these lines characteristic of his optical instruments, of the nature and behavior of light, of the earth's atmosphere, or of the sun? Fraunhofer had keen scientific curiosity, but his primary interest was that of an optician. His chief motive in studying stellar spectra was to discover if there were any difference in the refraction of light from different stars, a subject of contention at that time. His early investigations indicated need for further investigation and in 1823 he published more detailed results which proved conclusively that most of the features in solar and stellar spectra do not have their origin within the Earth's atmosphere. While Fraunhofer clearly indicated the fertility of research in stellar spectroscopy, other aspects of his work were more pressing and his early death (1826) prevented his resumption of these investigations; whence little progress in stellar classification can then be recorded for the next forty years or more.

But after the physicist Kirchoff had formulated his laws of spectrum analysis in 1859, astronomers became deeply appreciative of the importance of the Fraunhofer lines in stellar spectra. The new branches of astronomy, astrochemistry, and astrophysics, were opened-up to prospectors. Indeed, as is common in scientific progress, there had been early forerunners of the discovery of these laws, investigations semi-forgotten but for this revival of interest.

Already prior to 1753 the Scotchman, Thomas Melvill, had employed a prism for examining the spectra of flames into which he had intro-

duced various substances such as potash, alum, or salt. Unfortunately, all his spectra showed the sodium lines. As Agnes Clerke points out ("History of Astronomy in the Nineteenth Century," 131, 1902), the ubiquity of sodium hindered the progress of spectrum analysis considerably, for it was not realized just how minute an amount of this impurity is sufficient to become perceptible in the spectrum of any (other) source. The experiment was repeated by others with like results; in 1814 Fraunhofer had independently rediscovered this prevalence of the yellow line. This seemed to suggest that the line must be associated with some universal property of all matter—not of any particular element. Fox Talbot in 1826 was on the verge of stating the principle, in effect, that distinct spectral lines are associated with each element, and that the occurrence of the specific lines earmarked the presence of the particular element in the flame. Yet the sodium line appeared where, to the best of current knowledge, sodium was not present. Thirty years passed before it was shown (by William Swan) that only one part sodium in 180 million was sufficient to produce the highly tell-tale line.

The question of the telluric origin of the Fraunhofer lines arose early. In 1832 Brewster had showed (*Ed. Phil. Trans.*, XII, p. 528) that some of the lines were strengthened as the sun approached the horizon, proving their origin within our atmosphere. For the majority, however, this was not true, and astronomers debated the possibility of the lines arising in the solar atmosphere. In 1849, Foucault made an observation which came close to the discovery of Kirchoff's laws. Aspiring to demonstrate the coincidence of the dark solar D line with the bright line he had observed in the electric arc (again due to unsuspected sodium) he was surprised to note that the solar line became even darker when sunlight was passed across the arc. But he drew no specific conclusion from this remarkable observation. Stokes at Cambridge, however, surmised that the experiment revealed that a sodium atmosphere surrounded the sun, an hypothesis taught by Stokes and Lord Kelvin (William Thompson) already half a dozen years before the famous experiments of Kirchoff and Bunsen, who were unaware of the earlier developments (see Clerke, *loc. cit.*, p. 138), and before Kirchoff's enunciation of his deduced laws of spectrum analysis. Kirchoff himself was not slow to recognize the celestial application of these laws. In 1859 (*Monatsberichte, Ak. d. Wissenschaften, Berlin,* p. 664, 1859) he independently reached Stokes' conclusion that sodium is a constituent of the solar atmosphere; and in 1861 presented a paper before the Berlin academy showing that among the other constituents were iron, magnesium, calcium, and chromium, and, in smaller quantities, copper, zinc, barium, and nickel (*Abhandlungen d. K. Ak. d. Wissen., Berlin,* 1861). Kirchoff had contemplated measuring the entire solar spectrum between the Fraunhofer lines A and G. He, himself, did the entire work on the region from D to somewhat beyond F in which he measured over 640

lines, identified 138 of them with the chemical elements then known, and found that nearly 60 were iron lines. He estimated the probability of purely chance coincidences in the identifications of solar with laboratory lines at one in 10^{18}. Hampered by failing eyesight he assigned the remainder of the work of measuring the solar spectrum to his student, Hofmann. The final map (1863) was nearly eight feet long on which the relative line strengths were indicated in three gradations. The accompanying tables listed nearly 1500 lines giving line-intensities and line-widths in arbitrary steps. Some forty lines were identified as arising in the terrestrial atmosphere.

Early Spectral Classification

The first crude attempt at spectral classification came in 1860 when Donati at Florence visually observed "a family likeness" as regards observable spectrum lines among stars of the same color. Between that time and the complete development of the system of Miss Cannon's Henry Draper Catalogue, numerous more or less important classification schemes were adopted by various observers. Among the more significant ones are Secchi's (1866-68), which represents an extension and development of Rutherfurd's (1863), and Vogel's (1874), all relating to visual observations. With the advent of celestial photography there followed the investigations of Sir William and Lady Huggins, the later developments of Sir Norman Lockyer's classification system, and the evolution of the various Harvard systems, notably Miss Maury's (1897) on the one hand, and, on the other, the successive forerunners of Miss Cannon's adopted system: the Pickering system in 1890 and the Pickering-Fleming in 1897. A full description of these and others may be found in the article by R. H. Curtiss in the "Handbuch der Astrophysik" (Vol. 5, p. 1 ff, 1932).

In 1872, before the dry-plate technique had been developed, Henry Draper in New York had taken the first photographic spectrum of Vega. Huggins in England, who had pioneered in spectrum-photography with little success as early as 1863, obtained in 1876 the first dry-plate spectra. These first results he did not find very satisfactory, but by 1879 he had secured spectra of the whiter stars that opened-up the investigation of the hitherto unknown ultra-violet region. Sir Norman Lockyer, who in 1874 set up a new classification system based on the visual work of Vogel, in 1890 began photographic observations of his own for the purpose of developing this system. At Harvard, systematic spectrum-photography began under Pickering's direction in 1886 as part of the Henry Draper Memorial. Since then the spectra of well over a third of a million stars have been photographed, a few with a dispersion as high as eleven angstroms per millimeter at $H\gamma$, the majority with the shortest dispersion of 400 angstroms per millimeter.

Nearly all of the systems of spectral classification were "one-dimensional"; that is, the spectral classes were more or less correlated with one parameter only (color or temperature) but did not differentiate

effects in the spectra that were later to be found dependent on atmospheric pressure or luminosity. Perhaps the earliest clue to such differences may be found in Secchi's "Le Soleil" (p. 391, 1870), where he remarks concerning spectra of Type II, "Tout ces étoiles ne sont pas également faciles à étudier. Les raies noires sont extrêmement fines dans le spectre de Pollux et de la Chèvre; elles sont plus larges et plus faciles à reconnaitre dans Arcturus et Aldébaran." Although all of these are giant stars, the Mount Wilson and Victoria spectral types and absolute magnitudes for these four stars show a striking correlation with Secchi's remarks, even when allowance is made for the large range in spectral class (Table I). The differences that Secchi noted between line-strengths in Pollux and Arcturus (both H.D. class K0) might conceivably refer to lines like the relatively strong absolute magnitude lines SrII 4077 and 4215 which are the more pronounced in the more luminous stars.

TABLE I

Star	Secchi Remark	Mt. Wilson M	Victoria M	Trigonometric M
Capella	fine lines	0.7 G1	1.1 G1	—0.4
Pollux	fine lines	0.9 G8	2.4 G9	1.5
Arcturus	stronger lines	0.2 K0	0.2 K0	0.2
Aldebaran	stronger lines	0.0 K5	0.5 K8	0.1

The system proposed by Vogel (1874) was purported to be governed by the principle that "a rational classification of the stars according to their spectra is probably only to be obtained by proceeding from the standpoint that the phase of development of the particular body is in general mirrored in its spectrum" (Frost translation of Scheiner, "Astronomical Spectroscopy," p. 236, 1894). However, Vogel's system is closely correlated with Secchi's which was based wholly on observation unbiased by evolutionary theory. The theory Vogel envisaged followed from a suggestion by Zöllner in 1865. It assumed that as a star grows older it becomes cooler and therefore redder. Thus Vogel considered stars like Sirius and Vega young and the red stars comparatively old. But he offered no suggestion for the creation of the hot white stars. Others (*e.g.*, Stoney, *Proc. Roy. Soc.*, XVI, 31; XVII, 48, 1867) to the contrary, advocated the theory that the red stars were the younger; and eventually two sequences were postulated, an ascending and a descending temperature branch. A. Ritter (*Ann. d. Physik*, **20**, 155, 1883) is credited as the first to make this suggestion (*cf.*, Clerke, *loc. cit.*, p. 375), but he brought no specific observational evidence to support his hypothesis.

The schemes of classification developed by Sir Norman Lockyer between 1878 and 1915, when they were divorced from some of the hypotheses upon which they were ostensibly based, inspire admiration in the light of present-day developments on two-dimensional systems. In 1878 Lockyer envisaged a "dissociation theory" as a working hypothesis, according to which complex atoms in hot stellar atmospheres

("solar furnaces") are broken down into simpler forms possessing unknown spectra. Although he obviously did not have ions and free electrons in mind (the Bohr theory did not appear until 1913, thirty-five years later) Lockyer's hypothesis contains one of the essentials of the future ionization theory. It prompted Lockyer to arrange spectra in order of increasing complexity (one-dimensionally). Later his "meteoritic hypothesis" inspired his two-dimensional "temperature arch." According to this hypothesis, first proposed in 1887 and more fully developed in 1890 ("The Meteoritic Hypothesis," Macmillan and Co., London), meteorites are the fundamental building blocks of all stars. In the first stages of stellar formation meteorites collide under their mutual gravitational attraction. The earliest type stars will show only emission (called radiation) due to collision; as the swarm of colliding meteorites becomes more dense vaporization increases and absorption bands appear. At the top of the arch the highest vapor-temperatures are reached with the simplest absorption spectra; this stage "is brought about by the final change of all the motions of a swarm into heat"; then vaporous condensations due to gravity take place; "and finally the formation of a photosphere and crust." Thus his sequence of evolution went from cold stars to hot and gradually back to cool again; from large and diffuse systems at first, to small dense stars. In his early investigations, Lockyer simply re-evaluated the spectra classified by Vogel; but in 1890 he began obtaining stellar photographs of his own and already in 1892 he had classified 171 stars according to his own revised system. His principles of classification remained the same, but the specific spectral characteristics were more precisely described. In his third revision (1899-1902) in addition to the dissociation theory and the meteoritic hypothesis, chemical differences had also been taken into account. In 1902 he published classes for 470 of the brighter stars, and after that only minor revisions in the classification system were introduced before the appearance of his latest classifications of some 640 fainter stars (*Hill Obs. Bull.*, 1915-16). A star was assigned to the increasing temperature branch if "the protometallic (*i.e.*, enhanced) lines were relatively thick, hydrogen relatively thin" and to the decreasing temperature branch if "the protometallic lines were relatively thin, hydrogen relatively thick." These proved to be precisely the criteria used later at Mount Wilson for separating giant from dwarf stars. The stars on Lockyer's increasing temperature branch were stars of low density, those on the decreasing temperature branch of high density. The final typical "temperature arch" (Figure 1, *Hill Obs. Bull.*, No. 2, p. 1) is reproduced in Figure 1 where the corresponding Draper Classes for the stars chosen as typical by Lockyer are indicated. By and large the supergiants fall on the left, or Lockyer's increasing temperature branch; whereas the majority of the stars on the descending temperature branch are main sequence stars. Unfortunately, the limitation to apparently bright-stars rendered the choice of representative cool

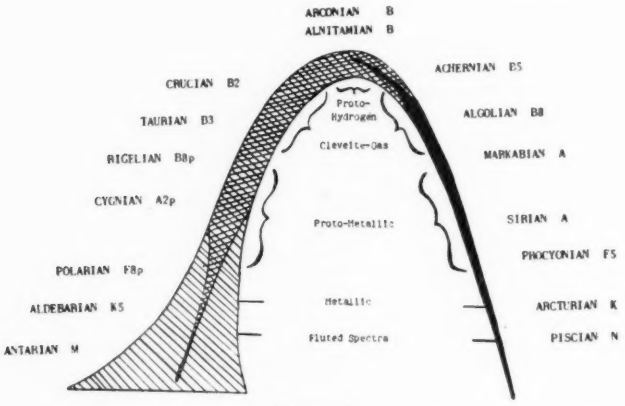


FIGURE 1
Lockyer's temperature arch (after Hill Observatory Bulletin 2, 1915).

stars on this sequence poor. In general, however, there is a decided correlation of Lockyer's classes with the Draper criteria, and some degree of absolute magnitude differentiation in his choice of standards except for the redder stars. One significant service rendered by this investigation was that Lockyer's classification was well correlated with temperature; since it was also correlated with the Harvard Draper-System, it may have put the latter more convenient system on a firmer footing; for the Draper system had been set up on a purely empirical basis, the spectra having been classified simply according to their progressive complexity of appearance.

In *Hill Obs. Bulletin* No. 6, 1919, Lockyer had made a detailed comparison of his groups with the Harvard classes for the stars they had in common. The results for his two extreme groups "Aldebaran stars" and "Arcturian stars" led him to conclude that the attempt at separation in the Harvard groups "is hopeless," twenty-two Aldebaran stars as well as forty-two Arcturian stars had all been classified K. In theory a separation should surely have existed. Although the work of Adams and his collaborators at Mount Wilson had already been in progress five years when Lockyer's final discouraging comparison with the Harvard system was made, he had not referred to the Mount Wilson papers at all. Had he done so, he would have found especially great satisfaction in Adams' paper, "Spectroscopic Evidence for the Existence of Two Classes of M-Type Stars" (*Mt. W. Comm.* No. 26; *Proc. N.A.S.*, **2**, 157, 1916), for it proved Lockyer's principle, despite refuting the legitimate membership of his chosen stars in the specific groups to which Lockyer had assigned them. Lockyer had noted in 1915, however, (*Hill Obs. Bull.* **2**) that stars with Miss Maury's *a*, *b*, and *c* designations, which Hertzsprung had shown to be absolute magnitude criteria,

were significantly distributed along his arch: the *c* stars on the ascending branch, the *b* (and *a*) at the top and on the descending branch.

In further support of his own results, Lockyer had pointed out (*Hill Obs. Bull.* 1, 1914) that Ludendorff's (*A.N.*, **190**, 193, 1912) discussion of Campbell's radial velocities, reflected the division of stars indicated by his own system, whereas the dependence of radial velocity on Harvard class was very unsatisfactory. Thus, for stars not near the peak of the temperature arch, all stars common to Lockyer's and Campbell's lists showed relative recessional velocities for stars on the ascending temperature branch and velocities of approach for those on the descending branch.

From the descriptions of Lockyer's criteria for classification as well as from the aforementioned correlations with other data, one might have

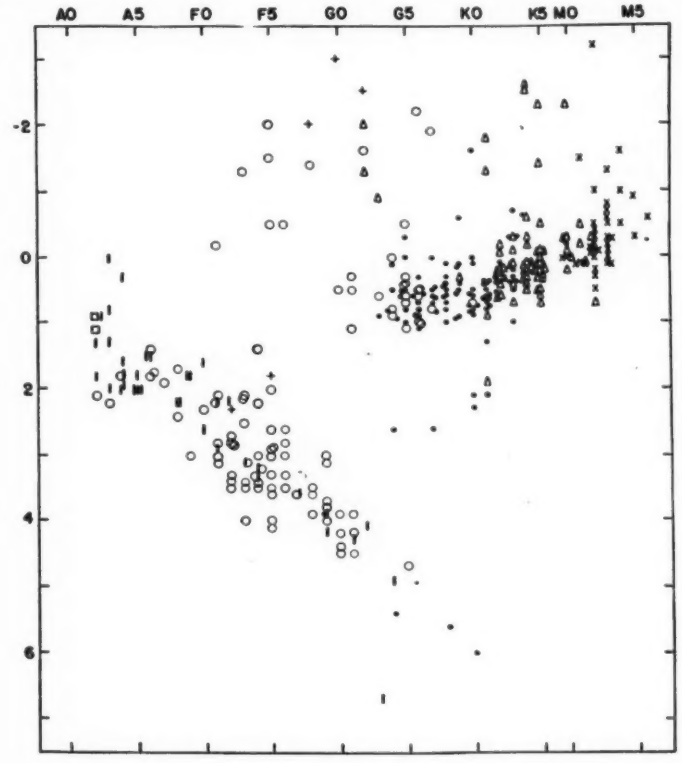


FIGURE 2

Mt. W. spectroscopic results; symbols for Lockyer "genera": crosses, Antarian; triangles, Aldebarian; plus signs, Polarian; open squares, Markabian; bars, Sirian; open circles, Procyonian; dots, Arcturian.

expected to find a significant correlation between absolute magnitude and Lockyer classes for stars now classified G0 or later. In Figure 2 the Mount Wilson absolute magnitudes and spectral classes of stars common to Lockyer are plotted with different symbols for each of Lockyer's "genera." Although there is considerable overlapping in the distributions of the various symbols, all except the "Sirian" types show a systematic progression from type to type. The Sirian stars, with one single giant-star exception, are main sequence stars with Mount Wilson types ranging from A through G4. Aldebaran stars on Lockyer's "ascending temperature" branch, prove to be only of later type than his Arcturian stars which are assigned to his descending temperature branch. Otherwise there is no absolute magnitude discrimination: the Arcturian stars include Mount Wilson supergiants, giants, subgiants, and dwarfs.

Whatever its faults in comparison with modern systems, Lockyer's outline of classification had merits beyond those of most of the others current in his time; for he encouraged the search for spectral differences which has subsequently become of utmost significance. His precepts for spectral classification were apparently neglected for three comparatively unimportant reasons: 1) The particular bright stars he chose as typical of his classes, or "genera" as he called them, were not all really typical; 2) although the system as a whole grouped like stars together and arranged the groups in an orderly sequence, the system was not accorded favor because it had been developed from untenable hypotheses; 3) the terminology he used in his finally adopted system was cumbersome, terms like Markabian and Algolian not lending themselves readily to decimal subclassification. In passing, it may be noted that the rejected Lockyer meteoritic theory has had recent revival in a different garb. The two hypotheses, 1) that many dark nebulae are partially composed of meteoritic material, and 2) that the apparently small round black nebulae, now known as "globules," are primordial stars vividly recall Lockyer's speculations.

Contemporaneously with most of Lockyer's work were the investigations of Huggins and Lady Huggins. They concentrated upon detailed study of comparatively few but very fine high-dispersion spectra, rather than on approximate classifications of large numbers of stars. Their work was consummated in "An Atlas of Representative Stellar Spectra from λ 4870 to λ 3300" (Wesley and Son, London, 1899). The accompanying text also contains a discussion of the evolutional order of the stars and the interpretation of their spectra. Bringing Lane's Law (1870) to bear, Lockyer stressed the argument already presented by him in 1891 (Presidential address, British Association for the Advancement of Science) that high temperature alone does not necessarily indicate the earliest stage of stellar evolution. Lane showed (Huggins, "Atlas," p. 68) that "So long as a stellar body remains subject to the laws of a purely gaseous body, its temperature will increase as conden-

sation advances. A time will come, however, when the expenditure by radiation will at last exceed the energy which can be made up by the shrinkage of the mass; the star will begin to cool, and when sufficiently condensed will give out less light and exhibit corresponding spectral changes." Thus, he pointed out, the effects of increasing gravity, especially density, in stellar atmospheres should play an important role in spectrum-development; and "must modify and may even mask . . . the changes . . . which would follow directly from differences of temperature." While Huggins suggests here that cooler (therefore, redder) stars than Sirius may be both larger and smaller, and that the larger should be the more massive, he has laid the theoretical foundation for the "Russell-Diagram." But he does not show by spectra or otherwise that he has actually found spectral differences between stars of the same color. What he infers is that the variations of H and K, upon which his classification rests to a large extent, are due primarily to differences in density and hence only indirectly to differences in temperature. The spectrum of Capella shown in the "Atlas," he finds "is not distinguishable from that of our sun," which was reproduced for comparison. Indeed, a close examination of these beautiful spectra reveals differences between the two only among the less prominent lines.

The most widely used has been the Henry Draper system perfected by Annie J. Cannon at Harvard. It is the final stage of development of the Pickering and the Pickering-Fleming systems. In this system the characteristics that might differentiate the highly luminous from the less luminous stars are recorded only by occasional foot-note remarks. Hence, the history of its development contributes less prominently to the discovery of spectroscopic luminosity-criteria than does the system proposed by Antonia Maury, also at Harvard. Miss Maury divided the spectra of some 680 bright stars into twenty-two distinct groups (I to XXII) forming a continuous sequence according to the progressive appearance of the prominent spectral lines. In addition, she gave *a, b,* and *c* divisions differentiating the stars of any group according to the sharpness of the lines (especially the hydrogen lines). In regard to the spectra of her Group XV (the late G and K types) she also remarked, "the stars of this group appear to fall into two divisions, exhibiting a slight difference in the degree of general absorption in the violet region. Of these divisions, α Bootis and α Cassiopeiae are, respectively, typical. In the first, the general absorption is slight; in the second, it is more conspicuous." The modern Mount Wilson data on these two stars are, respectively, $0^{M}.2K0$ and $-0^{M}.4G7$. While the difference in absolute luminosity is small, it is at least in the right direction. The corresponding trigonometric parallaxes, $0''.085$ and $0''.011$, indicate a much more conspicuous luminosity difference, namely from absolute magnitude -0.1 to -2.3.

Concerning the stars of her Group XV, Miss Maury had also commented on the difference between the two divisions in the intensity of

the lines λλ 4215 and 4078, now identified as the SrII "absolute-magnitude lines." Having found that she could separate the spectra of Group XV into two divisions, it seems a little surprising that she suggested no similar division among stars of the preceding group for which both Capella and the Sun (differing by over four magnitudes in absolute luminosity) were cited as the typical stars. To be sure, Miss Maury's remarks on individual stars indicated that she had noted many differences between Capella and the Sun, but here they seem to have been regarded as individual peculiarities rather than distinctions meriting special sub-divisions in her classification. Among the "Distinguishing Features" noted for the group intermediate between XIV and XV is a comment on the propensity for variation in λ 4078, and for both λλ 4078 and 4215 to appear stronger than in the typical stars.

In reviewing the works of Lockyer and of Miss Maury one ponders on how much farther these two investigators would have gone in the perfection of two-dimensional classification systems had the spectra at their disposal not been effectively limited to naked-eye stars and therefore to stars of moderately high absolute magnitude (brighter than about 5^M).

(To be continued)

On the Total Mass and Number of the Minor Planets

By C. H. SCHUETTE

Introduction

For many years the ever increasing number of the minor planets has often given rise to the question as to how great the total number of them may be and whether it is worth while continuing the observations and calculations in this respect. W. Baade[1] by means of the 100-inch telescope estimated the total number of all minor planets brighter than magnitude 19.0 to be 30,000-40,000. With our methods of today it will be impossible to carry out both the exact calculation and observation of such a great number. But many interesting orbits, such as 887 Alinda, 944 Hidalgo, 1221 Amor, Apollo, Adonis, Hermes, and many others would not have been discovered in the recent years if the observations had not been systematically continued. On account of this fact and by the new investigations of C. Hoffmeister and others (Ecliptical Meteor Streams and Zodiacal Light) the problem of the minor bodies of our solar system has acquired new interest. Therefore an attempt to determine the total mass and the number of the asteroids will be desirable.

Up to now there have been two possibilities to point out the total mass of the asteroids; first, there exists the determination by aid of the theory of perturbations, and the second possibility is the summation of the masses of all well-known minor planets. These methods lead to

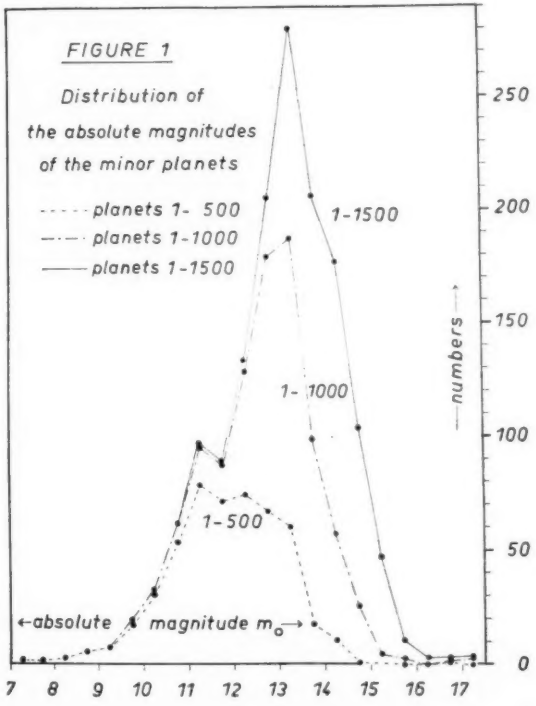
contradictory results of the total mass; the perturbation-method has given a value of about 1/10 mass of the earth, while the summation of all minor planets does not exceed 1/1000 of it. The discrepancy is very remarkable and, for this reason alone, it is necessary to get an estimation of the total mass and the number of the undiscovered planets by a new method.

The Observations

For this investigation the data of 1567 minor planets could be used including those of some new ones, and for some new elements I am much indebted to the Astronomische Rechen-institut, Heidelberg, including the three planets, Apollo, Adonis, and Hermes.

At first we must point out the limit of diameters for which all minor planets are known so that no further discoveries in these groups are to be expected. For this purpose all planets have been divided into groups according to their magnitude m_o at opposition, these groups having a range of 0.5 magnitude. Photographic m_o-values have been corrected for their color index (see page 440).

Figure 1 shows the distribution of the 3 groups, 1-500, 1-1000,



1-1500. It may be seen that the maximum of frequency falls to the left of m_o. Besides this it is evident that for values brighter than $m_o \sim 12^m$ scarcely any new discovery may be expected. Twenty years ago A. Klose[2] discussed the function of frequency of the absolute magnitudes of *all observed* minor planets, but this naturally denotes a selection, the small bodies still undiscovered having been omitted. But we need the function of distribution of the absolute magnitudes of *all asteroids*.

Determination of the Semi-Diameters and Correction for Color Index

Direct micrometrical determinations of the diameters of the minor planets have been made only for a few planets;[3] it is therefore necessary to use the photometric magnitudes and to accept a mean albedo. Such values were already given for 450 planets by J. Bauschinger and P. V. Neugebauer[4] in 1901 and were later on continued by G. Stracke.[5a, 5b] From No. 459 onwards all semi-diameters have been calculated anew from the mean magnitudes at opposition m_o on the supposition of a mean albedo of 0.240, according to G. Müller[6] and the formula:

$$\log \rho = 3.3135 + \log [a(a-1)] - m_o/5, \qquad (1)$$

ρ = semi-diameter and a meaning the greater semi-axis of the orbit. The values m_o are magnitudes of mean opposition, *i.e.*, the magnitude of a minor planet at the mean distance of a from the sun and the mean distance of $a-1$ from the earth at the same time. These magnitudes are usually given as visual; but of late there occur from planet No. 1282 onward also photographic m_o-values. The color index ($m_{phot} - m_{vis}$) of the minor planets is, as far as we know, positive. The most important determinations made of late are:

Color Index of Minor Planets

Planet	Color Index m	Authority
433 Eros	+ 0.60	G. Hartwig, *Astr. Nachr.*, **269**, 92 (1938)
4 Vesta	+ 1.11	H. Fischer, *Astr. Nachr.*, **273**, 130 (1942)
others	+ 1.03	H. Fischer, *Astr. Nachr.*, **272**, 127 (1491)

If we take a mean color index of $+1^m.0$, we get by means of the formula (1)

$$d\rho/\rho = +1/5\mathcal{M} = +0.46 \quad (\mathcal{M} = \text{Modulus of logarithms})$$

which means that all semi-diameters, determined by photographic m_o-values are to be increased by about 50%. In this way there are but 67 planets the semi-diameters of which must be corrected. Moreover, it is evident that an error of only $0^m.10$ in the magnitude will cause another one of 4.6% in the semi-diameters. Taking into consideration the mean color index and arranging the minor planets into groups of semi-diameters of the range of 5 km and into groups of 100 planets each, we find the numbers shown in Table 1.

TABLE 1

TABLE 1

DISTRIBUTION OF THE SEMI-DIAMETERS OF 1567 MINOR PLANETS, DIVIDED INTO GROUPS OF RANGE OF 5 KM AND FOR EACH 100 PLANETS (PHOTOGRAPHIC MAGNITUDES ARE CORRECTED FOR COLOR INDEX).

Planet No.	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	86-90	91-95	96-100	101-105	106-110	111-115	116-120	121-125	126-130	131-135	136-140	147-145	146-150	151-155	156-160	161-165	166-170	171-175	176-180	181-185	186-190	191-195	196-200	> 200	Years of Discoveries
	semi-diameter in km →																																									
	numbers																																									
1-100	..	..	..	1	..	2	2	4	9	5	3	9	6	**12**	9	6	3	5	2	4	2	2	1	2	2	1	.	1	1	2	.	.	.	.	1	.	.	.	.	.	.	3	1801-1868
101-200	..	1	1	..	4	9	8	8	10	**11**	10	8	6	5	4	6	1	1	1	2	3	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1868-1879
201-300	..	5	11	10	9	**14**	12	10	6	8	3	2	3	3	1	1	.	.	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1879-1890
301-400	..	2	6	8	**14**	**14**	8	11	7	11	5	3	2	.	.	.	.	.	1	3	1	1	2	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1890-1895
401-500	1	..	8	**14**	10	10	9	8	10	12	6	5	1	2	1	..	1	.	1	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1895-1903
501-600	..	4	4	9	13	12	**23**	10	6	6	2	4	3	1	.	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	.	3	1903-1906
601-700	..	9	9	**16**	11	12	15	8	6	5	1	3	2	.	.	.	1	.	.	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1906-1910
701-800	1	8	10	10	**19**	11	9	11	9	4	..	2	1	.	1	2	1	.	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1910-1915
801-900	..	**18**	17	16	17	15	10	1	1	1	1	1	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1915-1918
901-1000	..	18	**19**	14	17	15	10	1	1	1	1	1	1	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1918-1923
1001-1100	3	19	20	**22**	12	13	7	3	..	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1923-1928
1101-1200	4	**26**	20	10	16	12	5	2	2	.	1	1	..	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1928-1931
1201-1300	3	16	**29**	24	12	7	3	3	..	2	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1931-1934
1301-1400	..	**27**	25	20	14	6	4	3	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1934-1936
1401-1500	2	**35**	28	22	7	2	1	1	1	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1935-1938
1501-1564*	9	**25**	15	14	2	2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	2	.	.	.	.	.	3	1938-1943
	23	213	222	210	177	156	126	84	69	67	34	39	27	24	16	15	10	7	8	9	6	5	3	3	2	2	1	1	1	2												
									136		73		51		31		17		17		11		6		4		2		3												
Means**									104.5		62.0		41.0		24.0		17.0		14.0		8.5		5.0		3.0		2.5														

*and Apollo, Adonis, Hermes
**see also Table 2.

Clearly then from Stracke's table we can point out the trend of the recent discoveries towards the smaller semi-diameters. The slow increase or the decrease with the very small semi-diameters only indicates that here we are still in the very beginning of discoveries.

The maximum of frequency in each group of 100 planets is printed in boldface type. It is gradually dislocating to the left and in the perpendicular columns (constant semi-diameter) more and more towards the lower margin. Thus it is to be seen very clearly that the groups with the greater semi-diameters are nearly exhausted. During the last 50 years planets with semi-diameters exceeding 85 km have only seldom been discovered; they might be exhausted. But also in the last 25 years semi-diameters exceeding 40 km are very rare. The only somewhat greater one (since 1935) belongs to the Trojan-group, No. 1437 (group of 61-65 km). With a great probability an increase in the groups with semi-diameters of more than 40 km are scarcely to be expected, while, without any doubt, the number of small semi-diameters will increase by a great number of discoveries.

Figure 2 shows the numbers of frequency of the minor planets for the groups of the range of 5 km each, according to Table 1. Also this

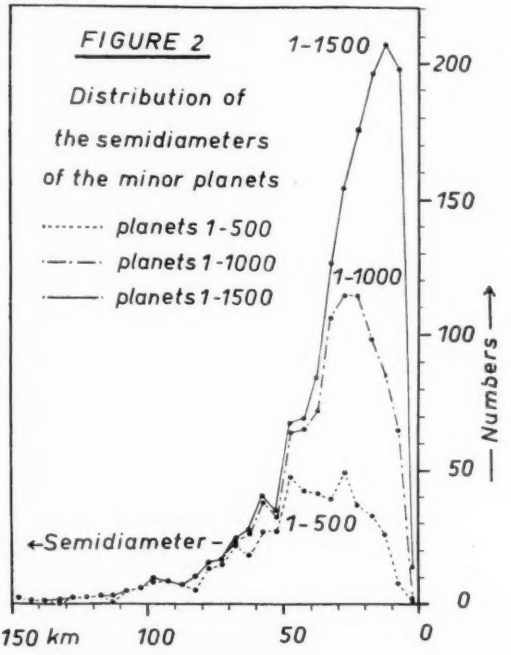


figure demonstrates that asteroids with semi-diameters of more than 50 km will scarcely be discovered.

How to Determine the Function of the Distribution of the Semi-Diameters

In order to be free from accidental fluctuations, *e.g.*, albedo, color index, etc., the groups have been taken together in intervals of the range of 10 km and then smoothed. Only the groups from 140 km down to 50 km, an alteration of which might not be expected, were used. These 10 values form the base for the determination of the function of distribution of semi-diameters. (See table 2.) At this

TABLE 2

Smoothed Numbers N_o of Observed Semi-Diameters

Semi-Diameter (km)	N_o (smoothed)
140	2.5
130	3.0
120	5.0
110	8.5
100	14.0
90	17.0
80	24.0
70	41.0
60	62.0
50	104.5

moment a comparison with the methods of stellar astronomy seems to lie close at hand, but circumstances are different. Plotting the values of log N_o and log ρ we discover that these values lie very nearly on a straight line, and the least-squares solution is as follows:

$$\log N_o = +8.284 - 3.638 \log \rho$$

This corresponds to the function of distribution

$$N_o = +1.926 \cdot 10^8 \cdot \rho^{-3.638}. \qquad (I)$$

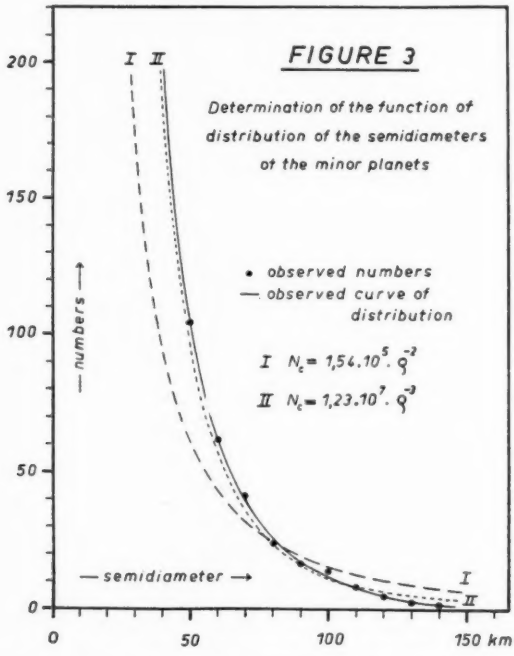
The differences between calculated N_c and observed N_o are shown below (see page 449).

But this solution is not yet satisfactory because the function of distribution is more complicated. For its further investigation the smoothed values N_o and ρ are shown in the diagram of Figure 3. We try a relationship suggested by the formula

$$N_c = \text{const} \cdot \rho^{-2}$$

in such a way that there is coincidence in the middle; but in this case we get too great numbers for great semi-diameters and too small ones for little semi-diameters. (See curve I in Figure 3.) The observed frequency will be much better represented by the formula:

$$N_c = \text{const} \cdot \rho^{-3} \text{ (see curve II in Figure 3).}$$



But even in this case the numbers for great semi-diameters are too great and those for the small ones too small. If we try to determine the constant and the exponent by the method of least squares, the solution leads to a value of about —3.6 for the exponent, as shown on page 443; but the solution of the normal equations is uncertain. Therefore, it is suitable to keep the dependency at ρ^{-3} and add a linear and an absolute term, so that we can suggest the following expression for the function of distribution:

$$N_c = A \cdot \rho^{-3} + B \cdot \rho + C.$$

From the 10 equations according to the smoothed values N_o (Table 2) the method of least squares gives the following function of distribution and mean errors of the coefficients:

$$N_c = \underset{\pm\ 0.368}{+\ 12.701} \cdot 10^6 \cdot \rho^{-3} \underset{\pm\ 0.0297}{-\ 0.0713}\ \rho \underset{\pm\ 3.55}{+\ 6.96} \qquad \text{(II)}$$

The computed residuals

$$(O - C)_{II}$$

found by this formula show a very good agreement, a variation of more than 2.0 occurring only once. (See table 4, page 449.)

Determinations of an Upper Limit of the Total Mass of the Minor Planets

Supposing the function of distribution, pointed out for the semi-diameters of the minor planets, to be valid also for all smaller semi-diameters, an upper limit for the total mass may easily be found. If V_0 is the volume of a single minor planet with the semi-diameter ρ(km), we have

$$V_0 = (4\pi/3)\,\rho^3. \tag{2}$$

If furthermore N is the number of all planets with the mean semi-diameter ρ, the total volume of *this group* necessarily is

$$V = V_0 \cdot N = (4\pi/3)\,\rho^3\,N. \tag{3}$$

When taking $N = f(\rho)$ as the function of distribution of the semi-diameters, the total volume of all minor planets from the semi-diameter of ρ_{max} up to ρ_{min} is

$$V = (4\pi/3) \int_{\rho_{min}}^{\rho_{max}} \rho^3 \cdot f(\rho) \cdot d\rho. \tag{4}$$

This equation can be integrated, in case the function $f(\rho)$ will permit.

To obtain the value of the mass it is moreover necessary to accept a value for the density d of the minor planets. We suggest the value $d = 2.65$ as the mean of the densities of Mars and Jupiter, which very nearly corresponds to half the density of the earth. Thus the total mass is

$$M = 2.65\,V.$$

If for abbreviation's sake the factor $(4/3) \cdot \pi \cdot 2.65 = 11.10$ is represented by D, the total mass is

$$M = D \int_{\rho_{min}}^{\rho_{max}} \rho^3\, f(\rho)\, d\rho. \tag{5}$$

The integration may easily be carried out with both functions of distribution (I) and (II) as given below; the resulting masses

$$M_I \text{ and } M_{II}$$

are

$$\left.\begin{aligned} M_I &= D \cdot A_I \cdot (\rho^{0.362}/0.362) \Big|_{\rho_{min}}^{\rho_{max}} \\ M_{II} &= D \cdot [A_{II} \cdot \rho + (B/5)\,\rho^5 + (C/4)\,\rho^4] \Big|_{\rho_{min}}^{\rho_{max}} \end{aligned}\right\} \tag{6}$$

As limits we take the values $\rho_{min} = 0$ and $\rho_{max} = 140$ km. Thus the 5 greatest planets are omitted and we must add their masses later on. If we put in the numbers, the greatest possible mass results are

$$M_I = 3.615 \cdot 10^{10} \text{ and } M_{II} = 1.864 \cdot 10^{10}$$

ρ being expressed in kms. If we, moreover, express the semi-diameter

of the sun in kms, we get $M_\odot = 1.985 \cdot 10^{18}$. The total mass of the minor planets in *units of the mass of the sun*, consequently, is

$$M_I = 1.82 \cdot 10^{-8} \cdot M_\odot \text{ and } M_{II} = 0.94 \cdot 10^{-8} \cdot M_\odot.$$

The omitted 5 planets, *viz.*, the planets **1, 2, 4, 10, 511**, have a mass together of $0.93 \cdot 10^{-9} \cdot M_\odot$, which means that they increase the value given above by about 10% at most.

Comparison with former Determinations of the Mass

It is very interesting to compare our value of the total mass with the most important earlier determinations. They are:

a. *Determinations of the mass by means of the theory of perturbations. P. Harzer*[7] derived from the discordances in the secular motion of the perihelion of Mars a total mass of the asteroids of $0.5 \cdot 10^{-6} \cdot \odot$ in good agreement with *S. Newcomb. H. Osten*[8] found from his theory of the minor planet 447 Valentine a value which is but half that of Harzer's, *i.e.*, $0.25 \cdot 10^{-6} \cdot \odot$. *G. Ravené*[9] also used the perturbations of the perihelion of Mars and determined the mass to be $0.27 \cdot 10^{-6}$ of the sun. Only *A. v. Brunn's*[10] value of $0.9 \cdot 10^{-8}$ sun-masses, obtained by other considerations, is considerably smaller.

b. *Determinations of the total mass by adding the masses of all observed minor planets. G. Stracke*[11] found a total mass of 1/847 of the earth for the sum of the first 1539 minor planets, which corresponds to $3.6 \cdot 10^{-9}$ masses of the sun. But he supposed the same density as that of the earth. In a similar way *M. Staude*[12] got $5.2 \cdot 10^{-9}$ sun masses. Both determinations are to be reduced to half the value, if—as in this investigation—we suppose as mean density of the asteroids only half of the density of the earth.

It may very easily be seen that in each case the first three determinations by the method of perturbations must give too great values of the mass because the observed perturbations cannot only be caused by the action of the minor planets. On the other hand the values of the total mass found by summing up the masses of the observed bodies only must be too small. But the authors of earlier investigations did not succeed in comprehending the mass of the still undiscovered bodies.

A Relation between ρ_{min} and the Total Mass M

But if ρ_{min} differs from zero, *i.e.*, if the smallest bodies are not infinitely small, the equations (6) immediately allow a relation between the total mass and the semi-diameter of the smallest bodies. In other words, we are able to derive from the total mass the smallest possible semi-diameter and *vice versa*. Both equations corresponding to the two function of distribution (I) and (II) follow:

$$\left.\begin{aligned} \rho_{min}^{0.362} &= \rho_{max}^{0.362} - (M_{I\,(max)} \cdot 0.362)/(D \cdot A_I) \\ A_{II} \cdot \rho_{min} + (C/4)\,\rho^4_{min} + (B/5)\,\rho^5_{min} &= (1/D)\,[M_{II(max)} - M_{II}]. \end{aligned}\right\} \quad (7)$$

Finding the value of ρ_{min} is rather troublesome. Therefore it is better

to start from ρ_{min} and to calculate the mass. If we presume as smallest semi-diameter that of 1/1000 mm, as for example *van Schewick*[13] pointed out for the zodiacal-light, and proceed to ever-increasing semi-diameters, we obtain the masses, which are seen in Table 3. (See also Figure 4.)

TABLE 3

ρ_{min} (km)	Mass (unit $10^{-8}\odot$) I	II
$1 \cdot 10^{-9} = 0.001$ mm	1.82	0.94
$1 \cdot 10^{-6} =$ 1 mm	1.82	0.94
$1 \cdot 10^{-3} =$ 1 m	1.80	0.94
1 km	1.52	0.93
10 km	1.14	0.88
20 km	0.94	0.80
30 km	0.78	0.73
40 km	0.69	0.65
50 km	0.59	0.57

It is evident that all bodies with very small semi-diameters do not

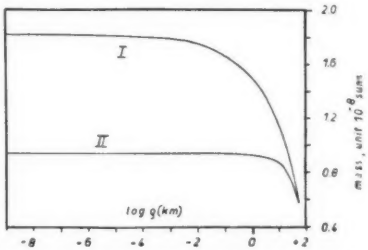


Figure 4. Totalmass of the minor planets

practically supply any amount of the total mass and that but from the semi-diameters of about 1 km and more a noticeable influence on the total mass can be realized.

Estimation of a Lower Limit of the Total Mass of the Minor Planets

Even without exactly knowing the function of distribution of the semi-diameters it is also possible to estimate the total mass. It was given by the equation (5):

$$M = D \int \rho^3 \cdot f(\rho) \cdot d\rho.$$

If now for $f(\rho)$ we put

$$f(\rho) = C \cdot \rho^n \tag{8}$$

C and n being still undefined and transfer this to the preceding equation, we get

$$M = D \cdot C \int_{\rho_{min}}^{\rho_{max}} \rho^{3+n} \cdot d\rho \tag{9}$$

or

$$M = D \cdot C \cdot \rho^{4+n}/(4+n) \Big|_{\rho_{min}}^{\rho_{max}} \tag{10}$$

On the right-hand side there are still both undefined constants C and n. For the solution we, therefore, need a second equation. This may be found by requiring that the still unknown function of distribution $f(\rho)$ must represent the observed distribution in a given place. This place may be for $\rho_o = 50$ km, with the observed number $N_o = 104.5$. Thus:

$$N_o = C \cdot \rho_o^n \text{ or } C = N_o/\rho_o^n. \tag{11}$$

Hence:

$$M = D \cdot N_o \rho^{4+n}/\rho_o^n \cdot (4+n). \tag{12}$$

We have again put $\rho_{min} = 0$ and written ρ for ρ_{max} for abbreviation's sake. If we now divide both sides of the last equation (12) by ρ_o^4 it takes the form

$$M/\rho_o^4 = D \cdot N_o/(4+n) \cdot (\rho/\rho_o)^{4+n}. \tag{13}$$

If for further abbreviation's sake we put

$$4+n = z \text{ and } \rho/\rho_o = F \tag{14}$$

the equation is

$$F^z/z = M/D \cdot N_o \cdot \rho_o^4. \tag{15}$$

The right side of the equation (15) being always positive, the function $f(z)$ must be > 0:

$$f(z) = (F^z/z) > 0. \tag{16}$$

If again we take the abbreviation:

$$B = M/D \cdot N_o \cdot \rho_o^4 \tag{17}$$

the positive solutions of the equation

$$f(z) = B \tag{18}$$

are to be found out.

We are able to show that for each given positive value of F the function of $f(z)$ possesses a maximum or minimum. If for this purpose we form $f'(z) = 0$, the corresponding value z_o is given by the equation:

$$z_o = \mathcal{M}/\log F. \qquad \mathcal{M} = \text{modulus of logarithms.} \tag{19}$$

Excluding the 3 greatest planets we take as upper limit $\rho_{max} = 175$ km and claim that the distribution shall be represented at the point $\rho_o = 50$ km; thus we get:

$$F = (\rho_{max}/\rho_o) = +3.50$$

and the maximum or minimum of the function $f(z)$ follows for $z_o = +0.798$. By forming $f''(z)$ we easily realize that a minimum can

be stated; hence this value of f(z) gives the smallest mass. The corresponding value of the minimum of f(z) is

$$f(z_o) = +3.40. \qquad (20)$$

Therefore $n = -3.202$ and the corresponding function of distribution will be

$$N = 2.88 \cdot 10^9 \cdot \rho^{-3.202}. \qquad (21) \quad (III)$$

The limit of the mass follows from (17) and (18)

$$M = 11.15 \cdot N_o \cdot \rho_o^4 \cdot f(z_o).$$

In order to show that by fixed ρ_{max} but with different values of ρ_o the mass changes only a little, the calculation has been made for different values of ρ_o. The data are given in the following small table:

ρ_o	N_o	z_o	$f(z_o)$	M (units of M⊙)
60 km	62.0	+0.933	+2.91	$1.32 \cdot 10^{-8}$
50	104.5	+0.798	+3.40	$1.25 \cdot 10^{-8}$
40	(203)	+0.678	+4.01	$1.15 \cdot 10^{-8}$

For $\rho_o = 40$ km the corresponding value N_o is not derived from the observations but from the calculation below (see page 450). These are, therefore, the values of the lower limit of the total mass, which may be enlarged by about 10% for the 3 greatest minor planets. (See page 446.) Yet there has always been put $\rho_{min} = 0$; the manner in which the mass diminishes if ρ_{min} is not equal to 0 has been shown above. (Page 446.)

Criticism of the Functions of Distribution and the Number of the New Discoveries to be Expected

The values of the total mass of the minor planets, found by several methods, lie between the limits from 0.94 to $1.82 \cdot 10^{-8}$ masses of the sun. The good agreement of these different masses makes it highly probable that the order is nearly correct. The 3 different functions of distribution for the numbers N of the minor planets with the semi-diameter ρ in km were:

(I) $N = +1.926 \cdot 10^8 \cdot \rho^{-3.638}$ from log N_o and log ρ
(II) $N = +12.701 \cdot 10^6 \cdot \rho^{-3} - 0.0713 \cdot \rho + 6.96$ from N_o and ρ
(III) $N = +2.88 \cdot 10^9 \cdot \rho^{-3.202}$ from the lowest limit of the total mass.

Now the comparison of the values, calculated with these 3 functions, with the numbers got from the observations may be of a special interest and is given in the following Table 4.

TABLE 4

Distribution of the Semi-Diameters

N_c = calculated numbers, N_o = observed numbers (smoothed)

ρ km	N_o (table 2)	N_c (I)	N_c (II)	N_c (III)	O − C (I)	O − C (II)	O − C (III)
140	2.5	3.0	1.6	3.9	−0.5	+0.9	−1.4
130	3.0	3.9	3.5	4.9	−0.9	−0.5	−1.9
120	5.0	5.3	5.8	6.3	−0.3	−0.8	−1.3
110	8.5	7.2	8.7	8.4	+1.3	−0.2	+0.5
100	14.0	10.2	12.5	11.4	+3.8	+1.5	+2.6
90	17.0	15.0	18.0	16.0	+2.0	−1.0	+1.0
80	24.0	23.0	26.1	23.2	+1.0	−2.1	+0.8
70	41.0	37.3	39.0	35.6	+3.7	+2.0	+5.4
60	62.0	65.5	61.5	58.3	−3.4	+0.5	+3.7
50	104.5	126.9	105.0	104.5	−22.4	−0.5	0.0

It is immediately to be seen that function II gives the best representation and the smallest residuals.

Now it is easy to calculate with these 3 functions the number of the smaller minor planets still to be expected, by subtracting the number of the observed planets, established in Table 1. The numbers calculated with functions (II) and (III) differ not very much, while by means of function (I) greater numbers result. This may be justified, in case further discoveries of planets should reveal planets of great semi-diameters of the group $\rho = 50$ km. The numbers calculated by the functions (II) and (III) of new-discoveries—still to be expected—may, therefore, be considered as lowest numbers.

TABLE 5

NUMBERS OF UNDISCOVERED MINOR PLANETS

(Semi-Diameters from 40 km to 10 km)

		N_o			undiscovered			m_o
ρ (km)	N_o	I	II	III	I	II	III	(visual)*
40	173	286	203	214	112	30	41	12.6
30	272	815	475	537	543	203	265	13.2
20	382	3 559	1 594	1 960	3 200	1 200	1 600	14.1
10	334	44 290	12 708	18 070	44 000	12 400	18 000	15.6

It is evident that these numbers are at best rough values that fix the still missing numbers only according to the order. The values m_o, added for the visual magnitudes are calculated on the supposition of a mean value of the greater semi-axis of the orbits of 3.1.

We see, however, that considering all minor planets with semi-diameters up to 20 km (mean value of group) or to the visual magnitude $m_o = 14$ there are at least about 1,500 minor planets missing. If we proceed by but 2 magnitudes, the number increases so rapidly that their complete research, calculation, and observation with the methods of today will be nearly without any hope of success.

I should like to express my sincere appreciation and gratitude to Dr. P. A. Schultz who has calculated the semi-diameters of about one thousand planets and who helped to finish this investigation within a short time.

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*for $a = 3.1$.

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MUNICH, GERMANY, ORTNITSTR. 15, APRIL 8, 1950.

The Time-Coordinate Transformation of Relativity, Derived from the Circumstances of the Aberration of Starlight

By PAUL E. WYLIE

The obvious way to explain the aberration of starlight is to select a star at the pole of the ecliptic and to construct a velocity-vector triangle as shown in Fig. 1. In this figure, c is the velocity of light, relative to the Earth; v is the velocity of the star, relative to the Earth; and >c is the resultant of the two. This explanation is, however, not used, because it leads to a velocity greater than c, this result violating the first (and obviously valid) postulate of the theory of relativity.

A similar vector-triangle may, however, be constructed by using distances (velocities multiplied by time), bearing in mind that the time is a function of the velocity of the observer relative to the source, and is

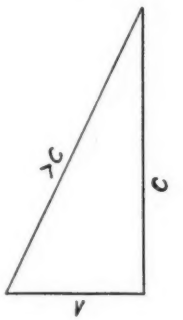

Fig. 1

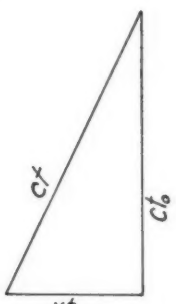

Fig. 2

thus not an absolute quantity. Fig. 2 shows this triangle. t_0 is the time involved when the distance remains constant (zero velocity); t is the

time of the observer corresponding to his velocity v. t is also the time involved in the hypotenuse, since it is only the horizontal leg that affects the value of the hypotenuse and causes it to differ from the vertical leg of the triangle.

Applying the Pythagorean theorem to Fig. 2, we obtain:

$$c^2t^2 = c^2t_o^2 + v^2t^2,$$

or

$$t^2 = \frac{c^2t_o^2}{c^2 - v^2}.$$

Dividing numerator and denominator each by c^2, we secure the expression

$$t^2 = \frac{t_o^2}{1 - (v^2/c^2)};$$

or, taking the root,

$$t = \frac{t_o}{\sqrt{1 - (v^2/c^2)}},$$

which is the formula of relativity for the transformation of the time coördinate.

Department of Astronomy, University of California, Los Angeles, California, September 24, 1950.

The Planets in December, 1950

By RAYMOND H. WILSON, JR.

Note: The time employed is Central Standard Time unless otherwise indicated. The phenomena have been chosen and described for the North American continent, and especially for the United States. The basic data have been taken principally from the *American Ephemeris and Nautical Almanac*.

Sun. The sun will spend this month close to its extreme winter declination of 23½ degrees south. The date of this turning-point, called the winter solstice, is December 22 at 4 A.M.

Moon. The phases of the moon will occur as follows:

Last Quarter	December	2	10 A.M.
New Moon		9	3 A.M.
First Quarter		16	2 A.M.
Full Moon		24	4 A.M.
Last Quarter		31	11 P.M.

The moon will be at perigee on December 8.

Evening and Morning Stars. Mars may still be glimpsed in the southwest twilight, when Jupiter will be just west of the meridian. Saturn will be rising shortly after midnight.

Mercury. On December 15 Mercury will stand at more than 20 degrees east of the sun and, hence, may be glimpsed up to an hour after sunset within a week of that date.

Venus. Having passed superior conjunction only last month, Venus will hardly be visible in the evening twilight, until, possibly, near the end of the month.

Mars. Mars will now be fainter than Fomalhaut but still enough ahead of the sun, in their eastward race, to remain above the southwest horizon until nearly 7 P.M.

Jupiter. This, the most conspicuous planet, will still be favorably situated for early evening observation.

Saturn. Quadrature of Saturn will occur on the day before Christmas, so that the planet will then be high on the meridian before sunrise.

Uranus. Uranus will be moving slowly west-northwestward at about midway between ϵ and μ Geminorum. It will stand in opposition to the sun on the 29th.

Neptune. Neptune will be moving southeastward at a degree and a half southeast of θ Viriginis.

Department of Mathematics, Temple University, Philadelphia, Pa.,
October 7, 1950.

Asteroid Notes

By HUGH S. RICE

At this time, there are a few bright asteroids for convenient observation by northern observers with small instruments, as follows: Planet 4, VESTA, is crossing the head of CETUS, with magnitude of 7. After having been located, it can be followed in the telescope even after the ephemeris runs out. 18 MELPOMENE, of magnitude 8.2, is at the Eridanus-Taurus boundary. 16 PSYCHE is in TAURUS at magnitude 9.2. On the evening of December 13 (in the U. S.) this asteroid will be in conjunction with ALPHA TAURI, and ¾° north of the star. Finally, minor planet 29, AMPHITRITE, of magnitude 8.7, is in AURIGA.

ASTEROID EPHEMERIDES

0^h U.T. Equinox 1950

4 VESTA

1950	α h m	δ ° ′
Nov. 5	3 0.2	+ 6 30
15	2 50.0	+ 6 4
25	2 40.7	+ 5 51
Dec. 5	2 33.2	+ 5 54
15	2 28.2	+ 6 15

18 MELPOMENE

1950	α h m	δ ° ′
Nov. 5	4 13.7	+ 0 20
15	4 5.3	— 0 37
25	3 56.0	— 0 57
Dec. 5	3 47.0	— 0 45
15	3 40.4	— 0 1

16 PSYCHE

1950	α h m	δ ° ′
Nov. 5	5 4.4	+18 13
15	4 58.0	+17 55
25	4 49.8	+17 38
Dec. 5	4 40.8	+17 22
15	4 31.9	+17 10
25	4 24.2	+17 4

29 AMPHITRITE

1950-51	α h m	δ ° ′
Nov. 15	5 21.7	+32 40
25	5 12.8	+32 59
Dev. 5	5 1.9	+33 2
15	4 50.5	+32 49
25	4 40.2	+32 22
Jan. 4	4 32.5	+31 45

Hayden Planetarium, American Museum of Natural History, New York,
1950 October 22.

Occultation Predictions for December, 1950

(Taken from the *American Ephemeris*)

The quantities in the columns *a* and *b* are given for the purpose of making these predictions useful for any place within 200 miles of the point indicated. The procedure is as follows: Subtract the longitude of the point given from the longitude of the place in question; multiply the result in degrees, taking the signs into account, by the quantity under *a* for the star to be observed; similarly, with the latitude, using *b*; apply the sum of the products, with its proper sign, to the Greenwich C.T., and obtain the predicted Greenwich Civil Time for the phenomenon at the place of observation. To obtain Eastern Standard Time it is necessary to subtract five hours; Central Standard Time, six hours, etc.

			IMMERSION				EMERSION			
Date 1950	Star	Mag.	Greenwich C.T.	*a*	*b*	Angle E from N	Greenwich C.T.	*a*	*b*	Angle E from N
			h m	m	m	°	h m	m	m	°
	Occultations Visible in Longitude +72° 30′, Latitude +42° 30′									
Dec. 3	80 Leon	6.4	9 1.0	−1.5	+0.3	109	10 12.1	−1.0	−1.4	328
18	π Pisc	5.6	20 23.2	−0.7	+1.8	79	21 26.2	−0.4	+2.4	211
21	66 Arie	6.1	8 36.6	+1.1	−3.9	145	9 2.8	−0.9	+1.7	198
21	BD+24°599	6.4	19 36.2	+0.6	+1.4	66	20 30.3	+0.2	+1.4	253
23	38 B.Auri	6.5	3 55.2	−2.0	+1.4	60	5 18.3	−2.0	−1.6	286
27	γ Canc	4.7	6 16.4	−1.6	−1.6	136	7 38.6	−2.1	−0.6	278
28	8 Leon	5.9	9 12.4	−1.3	−1.7	127	10 29.3	−1.0	−2.0	303
31	31 B.Virg	6.4	11 17.6	−1.0	−1.9	148	12 30.7	−1.4	−1.6	291
	Occultations Visible in Longitude +91° 0′, Latitude +40° 0′									
Dec. 3	80 Leon	6.4	8 42.2	−0.7	−0.4	134	9 51.3	−1.2	+0.2	294
5	50 Virg	6.2	12 10.8	−0.7	−1.0	150	13 18.5	−1.7	−0.1	288
23	38 B.Auri	6.5	3 18.0	−1.4	+2.5	52	4 39.9	−2.4	−0.4	280
27	γ Canc	4.7	5 52.7	−1.6	−2.8	158	6 51.0	−2.3	+2.6	242
28	8 Leon	5.9	8 58.5	−0.6	−3.3	168	10 0.3	−2.8	0.0	261
31	31 B.Virg	6.4	11 8.4	+0.6	−3.6	190	11 50.9	−3.5	+0.7	254
	Occultations Visible in Longitude +98° 0′, Latitude +31° 0′									
Dec. 3	80 Leon	6.4	8 51.3	−0.3	−3.3	178	9 30.7	−1.7	+2.8	246
5	BD−8°3495	6.4	11 16.2	..	..	57	11 35.6	..	..	20
6	214 G.Virg	6.4	12 9.8	−1.2	+0.7	99	13 8.5	−0.4	−1.2	334
23	38 B.Auri	6.5	2 49.8	−1.5	+1.8	69	4 18.8	−2.2	+1.1	256
23	47 B.Auri	6.1	6 39.2	−2.7	+1.9	52	7 54.0	−1.7	−3.0	305
	Occultations Visible in Longitude +120° 0′, Latitude +36° 0′									
Dec. 6	214 G.Virg	6.4	11 59.3	−0.2	+0.4	114	12 56.0	−0.3	−0.1	311
15	337 B.Aqar	6.4	22 59.7	−1.7	+1.6	78	0 9.0	−0.9	+2.3	203
16	342 B.Aqar	6.5	0 40.1	−2.2	+1.2	72	1 55.5	−0.9	+2.1	202
23	38 B.Auri	6.5	2 58.7	..	..	5	3 27.3	..	..	319
23	47 B.Auri	6.1	6 16.2	..	..	4	6 41.6	..	..	332
27	γ Canc	4.7	5 18.2	−1.4	−2.4	161	5 54.9	−0.1	+4.1	224

METEORS AND METEORITES

Meteor Notes from the American Meteor Society

By CHARLES P. OLIVIER, President

In our Society it is inevitable that there is a considerable change in membership and, even more, in the ability of active observers to continue their actual observation of meteors. This is due to change of occupation, moving to a city

environment, etc., as well as loss of interest. Hence, in different years, we are likely to have a new locality become the one where most is being done.

In 1950, due to the enthusiasm and perseverence of one young man, Charles E. Worley of Ottumwa, Iowa, his home town his surpassed any other locality. His own contribution up to September 20 has been 2012 meteors, fully observed and plotted. This is certainly the A.M.S. record for many years past. Working with him were Charles Ayres and Miss Marietta Eighme. The former has reported 625 meteors, all fully described and recorded but not plotted, and the latter has made counts of 315 meteors, which are available for studies of rates. Further, Worley, who is in school at St. Louis, has been instrumental in having James F. Jekel of Pacific, Mo., join the A.M.S. For 1950 he has already reported 435 meteors, fully recorded and plotted. In addition to the value of so many observations by a small group, the records submitted have a further value in that they were made following instructions carefully and the plotting is obviously good. Indeed, Worley and his friends deserve very high commendation for the excellent work done this year. Worley was already one of our most active observers having reported 94 meteors in 1947 and 1948, and 925 in 1949, the latter plotted and fully recorded.

As the 1950 work is so much more homogeneous than usual, I have prepared Table I which includes what was done up to September 13 and the records of which are here. Particular attention should be directed to the interval from July 17 to August 18, covering as it does the time when the Perseids are in evidence. Favored by exceptional weather and even more exceptional industry, this group has covered this period better, so far as I can remember, than it has ever been done by A.M.S. members. Indeed, I do not off-hand remember a record of any single observer anywhere who worked so often and successfully as Worley, for these weeks, in a single year. Hence we have here the material for a really excellent study of the cross-section of the Perseid stream traversed by the Earth in 1950.

Although I have already spent many hours deriving the radiants on the maps of Worley and Jekel, this work is time-consuming and it has been only partially completed. But as I wish to have at least part of the radiants, which can be derived, accompanying Table I, they are given in Table II. As a further remark, it can be seen from Table I that the large total number of meteors does not come from very high rates on a few nights but from long hours of observing on many nights. This adds greatly to their statistical value. In the table uncorrected rates are given. To secure corrected rates divide the uncorrected by F, the factor for the night. However, a further remark should be made. It is likely that a full observation, including plotting the meteor, took about one minute. Hence the rates of the plotted observations would need a considerable correction upwards to make them exactly comparable with those of Miss Eighme or others, who counted only. A few nights, when work lasted a half hour more or less, are omitted from Table I.

TABLE I

Charles E. Worley
Ottumwa, Iowa

Date m	d	Began	Ended	Min.	Met.	F	Rate	Date m	d	Began	Ended	Min.	Met.	F	Rate
2	16	13:00	15:35	130	17	1.0	8	3	27	12:45	15:20	75	12	0.7	10
2	18	12:30	13:30	60	4	1.0	4	4	19	11:45	12:45	60	6	1.0	6
3	17	12:35	13:35	60	5	0.8	5	4	20	13:15	15:15	75	13	1.0	10
3	25	12:55	13:55	60	6	0.7	6	6	6	12:00	13:15	75	15		12

Date m	d	Began	Ended	Min.	Met.	F	Rate	Date m	d	Began	Ended	Min.	Met.	F	Rate
6	7	10:15	12:30	75	7	0.8	6	7	29	11:00	11:45	45	9	0.3	..
6	9	11:45	12:45	60	15	1.0	15	7	31	10:35	13:35	180	31	0.5	10
6	10	12:00	12:45	45	11	1.0	15	8	1	9:10	14:15	305	66	0.7	13
6	12	12:00	14:50	170	40	0.9	14	8	2	9:15	13:30	255	46	0.9	11
6	15	11:15	12:45	90	10	0.9	7	8	5	9:45	12:35	135	27	1.0	12
6	19	13:30	15:00	90	20	1.0	13	8	6	9:00	12:30	210	50	1.0	14
6	20	12:00	12:35	35	6	1.0	10	8	8	9:35	15:35	360	80	0.9	13
6	25	13:15	14:15	60	13	1.0	13	8	9	9:05	14:05	300	85	1.0	17
7	5	10:30	11:30	60	11	0.8	11	8	10	9:00	15:00	360	130	1.0	22
7	6	10:10	12:00	110	18	1.0	10	8	11	11:40	12:40	60	10	0.2	..
7	7	9:20	13:30	200	36	0.7	11	8	12	8:35	14:15	300	148	0.8	30
7	8	9:55	10:55	60	6	0.5	6	8	14	9:15	12:20	185	62	0.9	20
7	10	10:30	11:35	65	9	0.6	8	8	15	9:00	14:00	300	110	1.0	22
7	11	10:50	14:50	240	50	1.0	12	8	16	9:00	12:00	180	50	0.9	17
7	13	13:05	13:45	40	10	1.0	15	8	18	10:00	13:00	180	51	1.0	17
7	14	11:15	14:45	210	54	1.0	15	8	20	9:00	12:00	165	33	0.8	12
7	17	10:50	13:20	120	25	0.9	12	9	2	8:20	11:00	160	25	0.8	9
7	20	9:00	14:00	275	56	0.7	13	9	3	9:10	11:40	150	25	0.9	10
7	22	9:30	15:00	330	71	0.8	13	9	4	8:20	12:20	240	50	1.0	12
7	23	10:20	14:00	220	54	0.8	15	9	5	8:20	13:30	310	65	1.0	13
7	24	11:55	12:25	30	8	0.6	16	9	6	8:55	14:05	310	60	1.0	12
7	25	10:55	13:25	150	25	0.5	10	9	7	9:40	13:10	210	31	0.8	9
7	26	12:00	12:30	30	3	0.3	..	9	8	14:00	16:30	150	30	0.8	12
7	27	9:45	12:00	75	6	0.3	..	9	13	8:30	14:10	280	64	1.0	14
7	28	9:30	12:00	150	9	0.4	..								

James F. Jekel
Pacific, Mo.

Date m	d	Began	Ended	Min.	Met.	F	Rate	Date m	d	Began	Ended	Min.	Met.	F	Rate
7	29	10:45	16:00	120	9	0.4	4	8	9	9:15	10:15	60	6	0.5	6
8	2	9:30	11:30	120	20	0.8	10	8	10	9:20	16:00	400	130	0.9	20
8	5	9:30	13:30	210	27	0.7	8	8	11	9:00	16:00	420	196	0.8	28
8	6	8:15	11:45	210	26	0.9	7								

Charles C. Ayres
Ottumwa, Iowa

Date m	d	Began	Ended	Min.	Met.	F	Rate	Date m	d	Began	Ended	Min.	Met.	F	Rate
6	19	9:35	11:35	120	7	0.9	4	7	23	9:50	12:10	140	23	0.7	10
6	21	9:45	11:45	120	13		6	7	24	11:10	12:15	65	14	0.7	13
6	24	11:00	14:10	190	15		5	7	25	10:20	11:30	70	4	0.4	3
7	1	10:00	10:45	45	4	0.6	5	7	31	9:30	10:30	60	4	0.6	4
7	3	11:30	12:30	60	2	1.0	2	8	1	8:25	13:05	280	54	0.7	12
7	5	10:20	12:05	105	18		10	8	2	10:35	13:30	175	27	0.7	9
7	6	10:10	11:50	100	12	0.8	7	8	3	10:00	11:30	90	16	0.7	11
7	8			30±	3		..	8	5	12:55	14:15	80	19	0.8	14
7	10	10:30	11:35	65	11	0.6	10	8	6	9:00	10:00	60	9	0.8	9
7	12	10:50	12:05	75	10	1.0	8	8	8	11:10	12:45	95	15	0.9	9
7	14	9:50	13:35	225	40	1.0	11	8	9	9:30	11:35	125	19	0.8	9
7	16	10:13			5	0.5	..	8	10	9:15	12:30	90	18	1.0	12
7	17	10:35	13:20	165	28	1.0	10	8	11	10:00	12:40	160	19	0.2	..
7	20	9:35	12:00	145	27	1.0	11	8	14	9:10	10:10	60	14	1.0	14
7	21	11:10	13:00	110	20	1.0	11	8	15	9:20	13:00	220	66	1.0	18
7	22	10:40	15:00	260	63		15	8	16	9:50	12:00	130	12+	1.0	..

Miss Marietta Eighme
Ottumwa, Iowa

Date m	d	Began	Ended	Min.	Met.	F	Rate	Date m	d	Began	Ended	Min.	Met.	F	Rate
6	14	10:00	11:15	75	12	0.9	10	8	6	9:00	12:00	180	24	1.0	8
7	21	11:10	13:00	110	19	1.0	10	8	9	9:10	11:35	145	28	1.0	11
7	23	10:00	12:20	140	12	0.6	5	8	10	10:00	12:30	150	55	1.0	22
7	24	11:10	12:20	70	13	0.8	11	8	13	10:00	11:30	90	47	0.9	31
7	25	10:20	11:30	70	4	0.5	3	8	14	10:00	11:20	80	38	0.8	28
7	31	10:35	11:05	30	2	0.5	4	8	16	9:52	11:22	90	23	1.0	16
8	2	9:45	11:10	85	10	0.9	7	8	18	10:00	12:00	120	28	1.0	14

TABLE II

No.	1950	α °	δ °	No. Meteors Acc.		Remarks
3105	Sept. 4.64	0	+16	6	FG	1 on Sept. 3, 5, 7; 242, 244, 523
3106	Sept. 4.64	6	+13	6	FG	1 on Sept. 3, 5; 244?, 242?
3107	Sept. 6.73	14	+18	8	G	1 on Sept. 7, 3 on Sept. 8
3108	Sept. 13.72	20	+ 7	4	FG	1 on Sept. 14
3109	Sept. 4.2	20	+49	6	FG	3 on Sept. 3, 3 on Sept. 4
3110	Sept. 6.73	27.5	+21	5	FG	1 on Sept. 4, 7, 8; 3000??
3111	Sept. 5.70	30	+23	6	G	1683?
3112	Sept. 6.73	32	— 5	4	FG	1 on Sept. 8; 2915
3113	Aug. 8.77	34	+54.3	9-6	FG	Perseids
3114	Aug. 10.75	43	+54.8	32	VG	Map I used; Perseids
3115	Aug. 10.75	43.8	+53.6	6-7	VG	Map III used; Perseids
3116	Aug. 8.77	44	+54.5	8-5	G	Perseids
3117	Aug. 10.75	45.0	+56.2	7	VG	Map III used
3118	Sept. 13.72	59	+48	6	G	
3119	Sept. 13.72	71	+35	4-7	F	
3120	Sept. 13.72	75	+10	3		2 on Sept. 13, 1 on Sept. 14
3121	Aug. 10.75	285	+58	4	G	1991, 1047, 2933?
3122	Aug. 6.70	292	+62	7	FG	3 on Aug. 5, 3 on Aug. 6, 1 on Aug. 8; 1993, 2114, 2929
3123	Aug. 15.2	295	+54	9	FG	4 on Aug. 14, 4 on Aug. 15, 1 on Aug. 9; 1467?
3124	July 25.76	298	+10.5	1		Stationary: 21
3125	July 22.76	321	+18	5-6	G	2 on July 20
3126	Aug. 7.7	325	+34	6	FG	3 on Aug. 6, 3 on Aug. 8; 450?
3127	Aug. 5.7	331	+22	8	G	1 on Aug. 3, 2 on Aug. 4; 1145
3128	Aug. 14.7	334	+50	6-4	G	3 on Aug. 15
3129	Sept. 6.73	335	+29.5	10	G	1 on Sept. 7
3130	Aug. 6.70	337	+44	5	G	2 on Aug. 8
3131	July 28.70	339	—14	7	G	2 on July 26, 1 on July 27; δ Aquarids
3132	Sept. 4.64	345	—10	7	G	
3133	Sept. 5.70	349	+ 8	4	G	
3134	Sept. 6.73	350	+ 6	3-4	G	1 on Sept. 7; 2429
3135	Sept. 13.72	350	+43	5-6	P	Off map
3136	Sept. 13.72	354	+14	3-5	F	1200
3137	Aug. 10.78	42.5	+54.1	32	G	Perseids
3138	Aug. 11.77	45.1	+55.1	115	G	Perseids

Notes on Table II—Radiants Nos. 3105 to 3136 are from the maps of Worley. Nos. 3137 and 3138 from Jekel's. In "Remarks" column, the meteors mentioned as seen on other nights are already included in the number given in Column 5. The other numbers refer to previously published A.M.S. radiants, which are considered probably confirmatory to the radiants now given. However, only a most superficial search has been made for confirmations as a really thorough one takes a great deal of time. It will be noted that 3 radiants are given for August 10 by Worley. Due to the Perseid radiant being near the edge of Map I of our series, the declination is less accurately determined than from plots on Map III. Two

sharp radiants appear on the latter, only one on the former. An excellent radiant could be derived by taking the mean of the three, as we would usually do for most observers.

Lastly what was accomplished by this small group of enthusiastic observers shows what could be done by similar groups, at least in parts of the country where skies are favorable. May we hope that this example will be followed elsewhere. Besides good weather, the outstanding reason for their success was a willingness to work long consecutive periods. Five hours on one night is usually so much better than one hour on five nights!

We have received the 13,000 meteor maps, ordered last summer. Hence all members can have their needs supplied. The author's paper on Telescopic Meteors has appeared in the last number of the *Proceedings of the American Philosophical Society*. As soon as the reprints arrive, copies will be sent to all persons who contributed and whose addresses are known. When the reprints containing Meteor Notes for 1950 are ready for distribution next spring, we intend to enclose a copy of the above paper to other members of the A.M.S. who have done good work this year.

Finally, will our members please particularly try to observe the Geminids whose maximum is due on December 12/13, but are active for some days before and after that date. Next to the Perseids, they are the most regular of our annual meteor showers and good rates should be obtained. As the main body of the Leonids is now near aphelion, few may be expected, but observations should be made from November 14 to 17 inclusive. There is no reason to expect a return of the Bielid meteors, this year or any other year, for that matter. The Quadrantids, which appear from January 1 to 4, inclusive, usually give good displays, if the maximum date can be hit. Cold weather discourages most of our members, but those who can or will stand it should get good results for those years when the Moon is absent. Our Florida observers certainly could work on these without hardship, so the Quadrantids are specially commended to their attention.

Flower Observatory of the University of Pennsylvania, Upper Darby, Pa., 1950 October 7.

Contributions of The Meteoritical Society

(Known Formerly as The Society for Research on Meteorites)

Edited by FREDERICK C. LEONARD
Department of Astronomy, University of California, Los Angeles 24

Some Observations on High-Speed Impact*

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ABSTRACT

This paper summarizes many of the experimental data that exist on phenomena associated with the impact of high-velocity particles; specifically, it discusses the impact of 20,000 ft./sec. particles produced by shaped charges, and the mechanics and energetics of crater formation. The probable mass of the

*Read at the 13th Meeting of the Society, Flagstaff and Barringer Meteorite Crater, Arizona, 1950 September 5-7.

meteorite that formed the Barringer Meteorite Crater of Arizona is calculated and found to be about 12,500 ordinary tons.

The principal conclusions drawn from the data are that (*a*) probably only a small fraction of the total mass of a meteorite is vaporized on impact; (*b*) a meteorite may or may not shatter on impact; (*c*) the volume of the crater fixes rather closely the striking energy of the meteorite; and (*d*) there is some likelihood that high-velocity meteorites do not imbed themselves in the craters that they form.

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1. *Introduction.*—There has been much interest recently, particularly among meteoriticists, in phenomena associated with the impact of high-velocity particles. Baldwin, *e.g.*, in his recent book,[1] has discussed in detail the formation of meteorite craters and has revealed certain relationships that seem to exist between craters produced by meteorites, explosions, and impacting projectiles. Interest in the probable mass, velocity, and final physical condition of the meteorite that produced the Barringer Meteorite Crater of Arizona has always been great. Stimulated by a desire to understand better what physically takes place when a high-velocity meteorite strikes the Earth, I have performed a number of experiments that throw light on this subject, and have examined many of the existing data pertinent to the subject. The present paper has been prepared with the thought that a description of the phenomena will be of considerable interest to meteoriticists.

2. *Nature of the Study.*—The primary purpose of this paper is to provide at least partial answers to some of the questions that concern meteoriticists. A few of these are:

(1) Does a meteorite vaporize when it strikes the Earth at high velocity?

(2) If it does not vaporize, does it shatter or suffer severe deformation on striking?

(3) Can one, from the size and shape of the crater, fix closely the mass, velocity, or energy of the meteorite that produced it?

(4) What chance does one have of locating the meteorite, and where should one look for it?

The velocities of meteorites that strike the Earth range from a few feet per second to perhaps 250,000 ft./sec.[1] Unfortunately, it has not yet been possible to produce, by artificial means, particles whose velocities approach even remotely the upper limit of this range. The fastest particles that have been studied are those produced by shaped charges whose velocities range from 20,000 ft./sec. to 30,000 ft./sec.[2] Rather extensive studies have been made up to velocities close to 6,000 ft./sec., since it is possible to fire balls, cylinders, and other missiles from ordinary guns at these velocities.[2] Until such time as very high-velocity particles are available for experimental purposes, the behavior of the very high-velocity particles must be inferred from results obtained at substantially lower velocities.

3. *The Energetics of High-Velocity Particles.*—The energy that a high-velocity particle possesses is of 2 kinds: (1) kinetic energy of translation and (2) chemical potential energy, which will be released if the particle burns. Upon striking a target, both forms of energy must play an important role in the interactions between target and particle. The latter as a source of energy will be considered in this section.

The heat of combustion of iron is 1,700 cal./gm., or roughly twice that of TNT. Looked at in another way, this is the energy that the same gram would

have if it were moving at a velocity of 10,000 ft./sec. Suppose, then, that, on impact, an iron meteorite vaporizes and burns; it may do so, since the kinetic energy of a particle of velocity 20,000 ft./sec. is more than twice the amount needed to vaporize it. On burning it would release a large amount of energy to its surroundings.[3]

4. *The Behavior of the Particle on Impact.*—A number of high-speed photographs (2,000 frames/sec.) have been taken of 20,000 ft./sec. iron particles impacting on a plaster of Paris target, in order to determine the extent of the burning. Some, but not extensive, burning was observed to occur. A number of the particles were recovered. These were essentially intact, and, from the appearance of the leading surfaces of the particles, it appeared that the burning was confined to that surface. Certainly the particles were not completely vaporized. It seems reasonable to conclude from these results that burning of the meteorite on impact does not contribute significantly to the total energy of the reaction.

If the meteorite neither vaporizes nor burns, what, then, happens to it? Does it shatter or does it hold together in a more-or-less single piece? The appearance of the recovered shaped-charge particles indicated that, in general, the particle suffers extreme deformation but will not necessarily break up. Whether it shatters or deforms depends to a large extent upon the ductility of the particle. I have found that hardened (65 Rockwell *C*) ball-bearings shot into lead targets shatter easily.[4] On the other hand, if the steel balls are made "dead soft," they will suffer extreme deformation without breaking apart. It was found that, as the striking velocity of the ball is increased, the sphere is deformed more and more, so that, at 5,000 ft./sec., it is literally turned inside out.

5. *The Nature of Craters.*—When a particle traveling at high velocity strikes a target, the most characteristic thing that it does is to produce a hole or crater. Sometimes this crater is simply a straight-sided hole whose cross-section is similar to that of the impacting particle; at other times, the crater is conical or cup-like in shape and has a more-or-less circular cross-section, regardless of the shape of the impacting particle. The cross-sectional area of the crater is very much greater than the cross-sectional area of the particle. The nature of the crater changes from the former shape to the latter as the impact velocity of the particle is increased.

The shape and size of the crater depend not only upon the velocity of the particle but also, to a very considerable extent, upon the physical properties of the target. Metals can and do flow when subjected to high compressive stresses; rock and rock-like substances, on the other hand, are usually crushed. The photograph in Fig. 1 shows typical craters produced by 20,000 ft./sec. particles in plaster of Paris. Neither the velocities nor the shapes and sizes of the particles are known exactly. High-speed photographs of the particles in flight indicated that velocities were about 20,000 ft./sec.; the particles were very irregular, and varied in size from about 1/16 inch to 3/8 inch in average diameter.

6. *The Mechanics of Crater Formation.*—What, then, are the mechanisms involved in crater formation? This matter has been the subject of much speculation, since few experimental data bearing on it exist. Baldwin[1] postulates that, if a meteorite strikes at a velocity in excess of the velocity of the shock-wave in the target, a violent explosion follows the penetration of the meteorite, and that, if the velocity of the meteorite is less than this velocity, enough energy will be dissipated in the material to prevent crater formation by such an explosion.

One, and perhaps a reasonable way, of looking at the mechanics of crater

FIG. 1
CRATERS PRODUCED IN PLASTER OF PARIS BY 20,000 FT./SEC. SHAPED-CHARGED STEEL PARTICLES

formation is to suppose that the size and shape of a crater depend primarily upon the stress-distribution existing in the target during and immediately following deceleration of the particle. It will be shown later that these stresses are undoubtedly much higher than the elastic limit for steel and the compressive strength of rock.

When a solid body is subjected to a load at a point, the distribution of shearing stress is roughly that shown in Fig. 2.[5] If it is assumed that the metal will

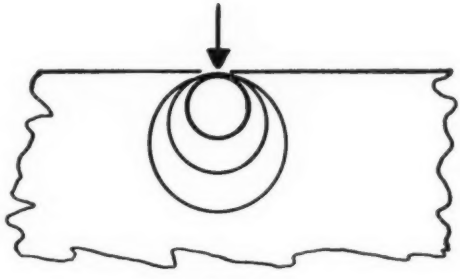

FIG. 2
SIMPLIFIED STRESS-DISTRIBUTION PRODUCED BY POINT LOADING

flow or that the rock will be crushed within a region in which the stress exceeds some value, then the shape of the crater should conform to the stress-distribution within the material. Thus, if the particle is stopped in a negligibly short distance, the crater will have approximately the shape of one of the curves shown in Fig. 2, with the exception that material near the free surface of the block will be pushed upward and out, since it is under little restraint. If, on the other hand, the particle travels a considerable distance before it is stopped, the force cannot be considered as acting at a single point; rather, both the location and the magnitude of the force will vary with time. If the magnitude of the force is assumed to decrease with the velocity (as the particle is being decelerated), then the contour of the crater will be the envelope of a series of shearing stress-distribution curves, somewhat as illustrated in Fig. 3. The exact shape of the crater will be

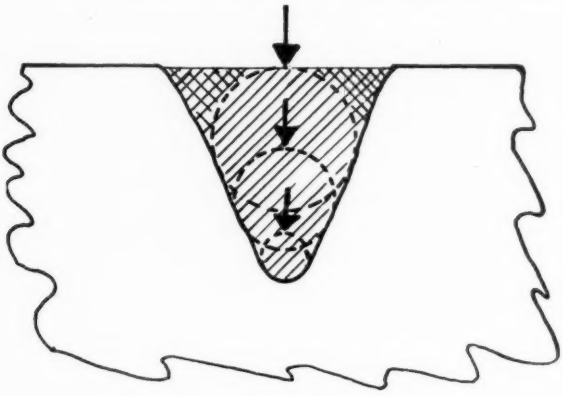

FIG. 3
POSSIBLE STRESS-DISTRIBUTION DURING CRATER FORMATION

closely related to the force function. That this relationship prevails has not yet been completely established experimentally.

Craters produced by shaped-charge particles striking steel are very nearly hemispherical in shape. In rock, the shape is very much more nearly conical. Thus, qualitatively at any rate, the validity of the foregoing assumptions is substantiated.

7. *The Energetics of Crater Formation.*—The earliest investigators[6] found that the volume of the crater produced by an impacting particle is directly proportional to the energy of the particle. Subsequent investigators have established specific values for lead and for rocks.[7] The craters produced by 17/32-inch-diameter steel balls at several velocities up to 5,000 ft./sec. have been studied, and the size of the crater has been found to increase rapidly with the velocity. Quantitative studies on rocks have been mostly in the velocity region 2,000-4,000 ft./sec. At even these velocities the craters are conical, with an initial cross-sectional area very much larger than that of the particle. For a velocity of 20,000 ft./sec., the general appearance of the craters is not characteristically different from that of the craters produced at the lower velocities.

It is usually assumed, in discussions of the formation of meteorite craters,

that, on impact, the kinetic energy of the meteorite produces a crater effect equivalent to that of an explosive charge having equal chemical energy. It is now possible to verify this assumption quantitatively both for lead and for rock.

The studies[4] on lead indicate that an impacting particle will displace 3.31×10^{-4} cubic inch of lead per foot-pound of energy; this result is equivalent to 0.82 cubic inch of lead per gram of TNT, since the heat of combustion of TNT is about 800 cal./gm. Some years ago, Burlot[8] detonated tetryl charges in lead blocks and determined the amount of lead displaced per gram of explosive. He found that 1 gm. of tetryl will displace 1.0 cubic inch of lead. The 2 values, 0.82 and 1.0, agree remarkably closely.

For soft rocks or sand the agreement is again good.[7] Workers at the Ballistics Research Laboratory, Aberdeen Proving Ground, found that the volumes of craters produced in soft rock by small-caliber ammunition range from 1.96×10^{-2} to 1.54×10^{-2} cubic inch of rock displaced per foot-pound of energy (or, in other energy units, 38.0 cubic inches per gram of explosive). Measurements[9] of craters in soil produced by high-explosive charges buried at a depth of 10 feet give an average crater volume of 38.8 cubic inches per gram of TNT.

The very good agreement between both of the preceding sets of values suggests strongly that (*a*) the mechanics of the formation of craters by impacting particles and by explosives is essentially the same; and (*b*) in both reactions approximately an equal part of the available energy goes into forming the crater.

Upon reflection, it is not surprising that the reactions are similar, since the magnitude and the duration of the applied forces are of the same order of magnitude in both cases. Take as an example a particle traveling with a velocity of 20,000 ft./sec.; assume that it strikes a target and penetrates to a depth of ½ inch, which corresponds closely to that of the craters produced in fine sandstone by shaped-charge particles. The magnitude and the duration of the force can be calculated only if one knows how the force varies as the particle makes its way into the target. This relationship is at present open to speculation, since no definitive data are available. A first approximation is that the force decreases linearly with the velocity.

Since the shape and the mass of the particle that produced a crater are not well established, no exact calculation of the forces can be made. Calculations, based on quite reasonable assumptions as to the probable mass and shape of the particle, indicate that stresses up to 10^6 lb./in.^{2} may very well exist, and that the time during which the stresses act is extremely short, perhaps not more than 1 millisecond. Both the magnitude and the duration of the stresses produced by explosive charges[10] are of similar orders of magnitude.

8. *Existing Meteorite Craters.*—The foregoing results permit certain deductions to be made about the meteorite that formed the Barringer Meteorite Crater of Arizona. The volume of this crater is about 10^{13} cubic inches. Using the constant, 2×10^{-2} cubic inch of rock displaced per foot-pound of energy, obtained at Aberdeen, we find that the energy required to form the Crater was approximately 10^{15} foot-pounds. If an impact velocity of 50,000 ft./sec. is assumed for the meteorite, then its mass was about 12,500 ordinary tons. This value is in fair agreement with the estimate of Wylie,[11] who has placed the mass of the meteorite at 8,500 tons for this impact velocity.

What are the chances of finding a meteorite in its crater? Baldwin[1] suggests that a high-velocity meteorite will be ejected from its crater by reaction of the tremendously compressed plug of matter immediately ahead of it. The shaped-charge-particle experiments seem to substantiate this point of view. In general,

no particles were found in the large shallow craters produced in plaster of Paris. A number of particles were, however, found lying on the surface of the target slab near the craters. These particles were probably ejected either by the reaction of a compressed plug of target material or by pressures produced by the burning of the particle or by a combination of the 2 effects. In view of these results, it seems reasonable to expect that large meteorites might be ejected, so that the chance of finding a meteorite in its crater would be very small. On the other hand, such extreme extrapolation, *i.e.*, from fractions of a gram to kilotons, is very risky and may not be valid in this case.

9. *Summary.*—What, then, are the most probable answers to the questions raised at the beginning of this paper?

(1) At most, only a small fraction of the total mass of a meteorite is vaporized on impact. The energy released by the burning does not contribute significantly to the energy involved in crater formation.

(2) Sufficient experimental data are not yet available to enable us to state conclusively whether a meteorite shatters on impact or merely suffers extreme deformation.

(3) From the volume of the crater, the striking energy of the meteorite can be fixed rather closely.

(4) There is some likelihood that high-velocity meteorites do not imbed themselves in the craters that they make, but rather are ejected and land at some distance from the crater, altho a definitive conclusion is not possible.

10. *Acknowledgments.*—In conclusion, I wish to acknowledge the valuable assistance given me by Dr. Marguerite Rogers of the Naval Ordnance Test Station, in the conduct of these experiments and in the interpretation of the data, and by Dr. E. J. Workman, President of the New Mexico School of Mines, for a number of stimulating discussions.

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[2] Birkhoff, G., MacDougall, D. P., Pugh, E. M., & Taylor, G. I., *Jour. Applied Phys.*, **19**, 563, 1948.

[3] Here we are concerned only with the burning of the particle, not with that of the target, since rock, *i.e.*, a non-inflammable material, is our principal concern. For impact against metal targets, the burning of ejected target material is an important source of energy.

[4] Work done while I was on the staff of the Research and Development Division, New Mexico School of Mines, Socorro.

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Meteor or Meteoric Cloud?*

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Abstract

A picture purporting to be a photograph of the great meteor of 1933 March 24 in flight was a photograph, not of the meteor itself, but of the meteoric cloud left in the wake of the meteor.

In the months immediately following the fall of the great meteor of 1933 March 24, a picture purporting to be a photograph of the meteor in flight appeared several times. The picture has appeared again in a recent (August 14, 1950) issue of *Life*, with the title, "The Fieriest Meteor Ever Frozen by Lens. . ."

This picture was taken by Mr. Charles M. Brown, foreman on the Lyon Ranch near Clayton, New Mexico. His story is that he was indoors, approaching the breakfast table, when he noticed the outdoors lighting up. He recalled that his camera, lying on the radio, was loaded; so he ran for the camera and then out of the door, to a point about 8 paces beyond, to clear the trees. Having opened the camera on the way out, he here pointed it at the bright object in the sky and snapped the picture.

The interval from the brilliant light, which attracts the attention of persons indoors, to the disappearance of a meteor is very short. Meteor workers are regularly interviewing persons who fail to cross a room and to reach a door in time to see a spectacular meteor; so some experienced meteor workers, on first reading Mr. Brown's story, suspected that he had photographed, not the meteor itself, but the cloud it left. The picture should, of course, tell which he photographed.

The meteor was of dazzling brightness, sufficient almost to blind observers, according to reports. The velocity was estimated as 20 miles per second (*P. A.*, **42**, 304, 1934), and the path was probably essentially straight. A snapshot of the meteor with the folding Brownie camera would show the head of the meteor elongated, since it would have moved nearly a mile during the time of the exposure, if the estimated velocity was correct. The intense light would have made the head photograph as black, instead of white, and surrounded by a large fogged and indistinct area. This phenomenon of "reversal" has been shown on photographs of lightning, of partial eclipses of the Sun, and of brilliant Leonid meteors. The Brown photograph does not fit this expected description. There is no reversal, or even special fogging, due to intense light. The head shows no elongation, due to rapid motion. The trail is far from straight.

Now let us consider what a photograph of the luminous cloud left by the meteor should show. Reports indicate that the cloud was about as bright as a daytime cloud in full sunshine; some say brighter, but at night the apparent brightness would have been exaggerated. Photographs known to be of the cloud show the trail, with a definite enlargement, presumably where the meteor burst, at the end. The upper-air currents bent the trail, and accounts agree that they moved the cloud as a whole very rapidly. The Brown photograph (*P. A.*, **42**, 291, 1934) can be compared with the Latham photograph of the cloud (*loc. cit.*, p. 299), the latter having been taken about 2 minutes after the passage of the meteor. In both pictures, the brightest portion is the enlarged cloud toward the

*Read at the 13th Meeting of the Society, Flagstaff and Barringer Meteorite Crater, Arizona, 1950 September 5-7.

top. In both, the trail, extending downward, is curved noticeably, but more in the Latham picture. The brightest portion in one picture is obviously about the same as the brightest portion in the other. Neither could have been appreciably brighter than a cloud in full sunlight, whereas the meteor itself looked like a "piece broken from the Sun."

To conclude: Mr. Brown did not perform the miraculous feat of getting his camera and opening it, going outdoors and beyond the trees, and snapping a picture of the meteor, all after the time of noticing the light from indoors and before the time of disappearance of the meteor. The picture shows that the intensity of the light and the general appearance were those of a meteoric cloud, and not at all those of a meteor.

We must give Mr. Brown credit, however, for snapping the most prompt picture of the cloud. In the Brown picture, altho the trail is curved noticeably, the edges of the cloud are sharp, whereas in the Latham picture, taken only some 2 minutes after the disappearance of the meteor, the edges have been broken and roughened by the air currents.

The meteor workers who from the first considered the Brown photograph to be a picture of a cloud did not publish that fact in 1933 or 1934, because they did not wish to embarrass friends who had accepted Mr. Brown's story as literally correct. Two or three years later, one of those workers said that he had prepared a rough draft of an article showing that the picture was a photograph of the meteoric cloud, but for some reason that we do not know, the article was not published. The picture has been discussed several times in informal groups at scientific meetings, and it has been referred to in correspondence, but, as far as we know, this is the first formal paper on the subject.†

1950 August 29

Fire from Heaven?*

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Abstract

When heat is reported in connection with the fall of any ordinary meteorite, it is always found that the alleged meteorite is not a meteorite at all, but rather a "meteorong"!

A few years ago, in the late spring, newspapers carried a story under the heading "Fiery Missile From Heaven Scorches Tomato Plants." The story related that a fiery meteorite had struck in a field of tomatoes near Columbus Junction, Iowa, the heat killing all the plants in a circular area about 25 feet across.

As Columbus Junction is within easy driving distance of Iowa City, the writer, with a man from the Iowa Geological Survey, visited the locality promptly. The owner of the field was glad to take us to the area of dead plants. He

†Under date of September 28, 1950, a representative of the Editors of *Life* writes: "You are right that 'the fieriest meteor ever frozen by lens,' which we pictured on p. 35 of our August 14th issue, is not the meteor itself, but a cloud of smoke left in the sky by the meteor. We appreciate your calling this point to our attention and regret only that space limitations prevent us from sharing your interesting information with our readers, thru our Letters Column. . . ."

*Read at the 13th Meeting of the Society, Flagstaff and Barringer Meteorite Crater, Arizona, 1950 September 5-7.

said at once that the diameter of the dead-plant area was greater than it was when he had found it a day or two earlier. At the edge of this area were plants just beginning to wilt. On pulling these up, it was found that the roots were dead, altho the upper part of each plant was nearly normal. This fact showed that a highly infectious disease of the roots was spreading from the center of the area, killing all the plants as they were reached. There are several diseases that might kill tomato plants in this way; so a few specimens were sent to the Iowa State College of Agriculture for the benefit of the owner of the field.

On July 3, 1950, we were notified that a fiery missile had struck in a cornfield near Brooklyn, Iowa, killing everything in an area about 2 paces across and doing some damage in a larger area. There was considerable fungus in the center of the area, some of which was sent to us.

As I was in the hospital at the time, the letter was not even promptly answered, and no visit to the area of the dead corn was possible. We did, however, consult an expert in diseases of corn some time later, showing him the fungus that had been sent from the locality. The expert told us that growing corn is subject to attack by very few diseases, being much more resistant than tomatoes. He had two suggestions to explain the dead corn.

The first suggestion was lightning, which he believed might kill everything in a circle that size. The other was Pythium stalk-rot, a highly infectious disease, which sometimes appears as far north as Brooklyn, Iowa. In either case, the dead plants would have been attacked promptly by fungus, as had been the sample submitted with the report.

The fall of a meteorite, strictly speaking, is not accompanied by heat. To have heat reach the ground, the meteorite must be so large that the luminous phase continues to the ground, and this statement means that the body must approach crater-producing size. When heat is reported in connection with the fall of any ordinary meteorite, we always find that the supposed meteorite is not a meteorite but what Dr. F. C. Leonard calls a "meteorong"!

1950 August 29

Air Drag on Cubes at Mach Numbers 0.5 to 3.5* (Abstract)

JOHN S. RINEHART
Naval Ordnance Test Station, China Lake, California,
and
GEORGE E. HANSCHE
Sandia Base, Albuquerque, New Mexico

The air drag on 2 sizes of steel cubes, ¼ inch and ⅜ inch on a side, has been determined in the approximate range from Mach Number 0.5 to 3.5. The drag force on the cube was taken equal to $C_D A v^2 \rho$, where C_D is the drag coefficient; ρ, the density of the air; and v, the velocity of the cube. The data did not yield an explicit value of the drag coefficient, but rather an average value of the quantity, $C_D A$, for a rotating cube, where A is proportional to the area of the cube. An average value for A of $1.50d^2$, where d is the length of one edge of the

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*Read at the 13th Meeting of the Society, 1950 September 5-7. The experimental work was done while the authors were on the staff of the New Mexico School of Mines in Albuquerque.

The "Mach Number" is the ratio of the velocity of a body in a given medium to that of sound in the same medium.

cube, is assumed, and C_D is calculated. The 2 sizes of cubes give essentially equal values for C_D at corresponding Mach Numbers.

The general form of the C_D curve follows closely that of the curve for spheres obtained by Charters and Thomas.[1] The transition from subsonic to supersonic velocities takes place over a relatively wide range of velocities, approximately from Mach Number 0.8 to 1.3. In passing thru the transonic region, C_D increases from a subsonic value of about 0.42 to a supersonic value of 0.63. The drag force on a cube at supersonic velocities is approximately 1.5 times that on a sphere of equal mass.

Appointments for the 1950-54 Term

At the first meeting of the Council for the 1950-54 term, which was held at the Barringer Meteorite Crater on the afternoon of 1950 September 7, immediately after the adjournment of the 13th Meeting of the Society, and at which President Brady, Secretary Russell, Treasurer Buddhue, Editor Leonard, Councilor Bauer, and Councilor (Ex-President) King were present, the following appointments were made for the 1950-54 term. (The name of the chairman of each committee is given first.)

Representative of the Society in the Council of the A.A.A.S. and in that of its Pacific Division: A. S. King.

Representative of the Society in the Council of the Southwestern Division of the A.A.A.S.: L. F. Brady.

STANDING COMMITTEES OF THE SOCIETY

Membership and Fellowship: O. E. Monnig, President L. F. Brady *(ex officio)*, H. Brown, J. D. Buddhue, E. P. Henderson, and Secretary J. A. Russell *(ex officio)*.

Finance and Endowment: J. Kaplan, B. Barringer, President L. F. Brady *(ex officio)*, Treasurer J. D. Buddhue *(ex officio)*, I. duPont, J. W. Higgins, P. J. McGough, and O. E. Monnig.

Publications: Editor F. C. Leonard *(ex officio)*, President L. F. Brady *(ex officio)*, H. Brown, B. J. Finnegan, C. H. Gingrich, L. LaPaz, and J. A. Russell.

SPECIAL COMMITTEES OF THE SOCIETY

Revision of the Articles of Incorporation: N. Schwartz, F. C. Leonard, and Secretary J. A. Russell *(ex officio)*.

General Catalog of the Meteoritic Falls of the World: F. C. Leonard, L. F. Brady, L. LaPaz, and J. A. Russell.

Textbook on Meteoritics: F. C. Leonard, L. LaPaz (vice-chairman), C. A. Bauer, C. W. Beck, J. D. Buddhue, D. Hoffleit, G. J. Neuerburg, and J. A. Russell.

Matters concerning the Barringer Meteorite Crater: D. M. Barringer, L. F. Brady (vice-chairman), T. E. Johnson, A. S. King, C. O. Lampland, and L. LaPaz.

JOHN A. RUSSELL, *Secretary*

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[1] A. C. Charters & R. N. Thomas, "The Aerodynamic Performance of Small Spheres from Subsonic to High Supersonic Velocities," *Jour. Aeronautical Sciences*, **12**, 468, 1945.

The Name of the Barringer Meteorite Crater of Arizona

At the conclusion of the first session of the 13th Meeting of the Society, held at the Museum of Northern Arizona, Flagstaff, on the morning of 1950 September 5, it was unanimously voted by the members present that it is the official recommendation of the Meteoritical Society that the name of the famous meteorite crater near Canyon Diablo, Coconino County, Arizona, be legally changed from "Meteor Crater," "Crater Mound," "Coon Butte," or any other appellation that is or has been applied to it, to the "Barringer Meteorite Crater," in tribute to the pioneering work and in memory of the late Daniel Moreau Barringer, who originally proposed and ably defended the meteoritic hypothesis of the origin of the Crater and who was largely responsible for the acceptance of that hypothesis.

At the first meeting of the Council of the Society for the 1950-54 term, held on the north rim of the Crater immediately after the adjournment of the 13th Meeting of the Society, on the afternoon of 1950 September 7, a special committee of the Society, called the "Committee on Matters concerning the Barringer Meteorite Crater," was established, and the following members were appointed to serve on it during the current term: Mr. D. Moreau Barringer (Chairman), President L. F. Brady (Vice-Chairman), Mr. Theodore E. Johnson (the Curator of the Crater and its museum), Councilor (Ex-President) Arthur S. King, Dr. Carl O. Lampland, and Vice-President Lincoln LaPaz.

Doubless one of the first things that this committee will do will be to transmit the recommendation of the Society to the federal authority in Washington, D. C., empowered to effect the proposed change in the legal name of the Crater.

It is to be understood, however, that the name of the *fall of meteorites* that caused the Crater and is concentric with it will, for obvious reasons, continue to be known as the "Canyon Diablo, Arizona," fall.—F.C.L.

The ECN of the Chubb Crater of Quebec, Canada (+737,613)

In a private letter dated 1950 September 11, Dr. V. Ben Meen, Director, Royal Ontario Museum of Geology and Mineralogy, Toronto, Ontario, Canada, writes that the geographic coördinates of the Chubb Crater of Quebec, Canada, to which reference was made in 2 notes by the undersigned in the October instalment of *C.M.S.*, are

$$\lambda = +73^\circ\ 40',\ \phi = +61^\circ\ 17'.$$

The equatorial coördinate number (ECN) of the Crater is, then, +737,613.—F.C.L.

New Prices of Complete (Back) Volumes of C.M.S.

At its sessions held in connection with the 13th Meeting of the Society, in September, 1950, the Council ruled that *complete (back) volumes only*, of *C.M.S.*, may henceforth be purchased by members of the Society and by others at *half price—i.e.*, at the rate of $1.00 per annual number or fascicle instead of at the current rate, or at the rate for *single* fascicles, of $2.00. All of the fascicles of Vols. 1, 2, and 3 are still available, with the single exception of Vol. 1, No. 2, Whole No. 2, for 1936, which is, unfortunately, out of print. Nos. 1 and 3 of Vol. 1 (for 1935 and 1937, respectively) may still be purchased for $2.00, however; Vol. 2, Nos. 1-4 (1938-41), for $4.00; and Vol. 3, Nos. 1-5 (1942-46), for $5.00. Orders, *which must be accompanied by remittances made payable to The Meteoritical Society*, for any or all of the forenamed back volumes of *C.M.S.*, should be

sent to the Secretary of the Society, Dr. John A. Russell, Department of Astronomy, University of Southern California, Los Angeles 7, California.

President of the Society: L. F. Brady, 922½ Forest Avenue, Tempe, Arizona
Secretary of the Society: John A. Russell, Department of Astronomy, University of Southern California, Los Angeles 7, California

Comet Notes

By G. VAN BIESBROECK

There are no known comets in reach of ordinary telescopes at this time. Except for a list of faint periodic comets found earlier near their expected positions 1950 has been poor in discoveries. Comet 1950 *b* (Minkowski) is the only new one found this year and it is now out of reach until next year, after recently disappearing in the evening sky.

Periodic Comet 1950 *a* (d'Arrest) is now (Oct. 10) reduced to 14th magnitude. It shows a well-condensed nucleus and a broad fan-shaped tail, three minutes long in the first quadrant.

Periodic Comet 1950 *d* (Daniel) is the next in brightness, having reached nearly 15th magnitude (Oct. 10). Its nucleus is fuzzy and it is surrounded by a very diffuse coma extending mostly towards the southwest vaguely suggesting a tail in that direction.

Periodic Comet 1950 *c* (Wolf) remains around magnitude 18 and shows as an ill-defined round star very little different from the many small extra-galactic nebulae which are present in that part of the sky.

Periodic Comet 1950 *e* (Encke) is still fainter than 18th magnitude but before long it should brighten up rapidly.

Williams Bay, Wisconsin, 1950 October 11.

Communications and Comments

Under this heading we shall publish from time to time such material as does not properly fall under any of the established headings of this journal. Here, too, may be found, when occasion arises, articles which the editor may not be willing to give sanction to but which, nevertheless, may be provocative of thought along new lines.

Recent Peculiar Atmospheric Conditions

Up to the present time, this year, the sky has been almost continuously cloudy in this part of the country, and there have been few clear starlight nights, so that good observing opportunities have been lacking. Occasionally, with the approach of darkness it was possible to do a little telescopic observing, but very often slight cloudiness would obscure the view.

The condition has also greatly interfered with solar observation, although frequently the Sun has been visible at some time during breaks in the clouds, necessitating altertness to take advantage of any such chances. Thus, for the month of August my record shows 29 observing days, many of which would have been missed but for the reason given.

Even on clear days (and few have been so throughout) the atmosphere has been more or less dense, with seeing mostly indifferent. Too, the cloudiness has been of rather peculiar character, varying between a state of fogginess to irregular flocculence—attributable to an excessive admixture of water vapor; while the temperatures have been as a rule below normal.

Exceptional was the very clear evening of September 17, when the twin cluster in Perseus was remarkably well seen with power 40 of my 1½-inch "periscopic" ocular. The morning following the first appearance of the bluish Sun on the afternoon of September 24, for some unknown reason the seeing was superb, enabling the smallest spots to be discerned with power 61 on my four-inch telescope, and which were verified with eyepieces of greater power.

Regarding this very exceptional aspect of the Sun (a phenomenon which was repeated during the next afternoon for a short time), the cloudiness was of uniform consistence, like a thick fog, and not dissimilar to what I have often noticed in the smoky city of Pittsburgh, the coloration possibly caused by particles of ice, and the effect entirely spectral. The blue tint ranged between light violet and pale azure, and was beautifully seen through my long inverting binoculars of power 15, without any other screen to affect the color, the stereoscopic property making the Sun appear as a globe, with the limb sharply defined. A description of these binoculars was published some years ago by the Astronomical Society of the Pacific, and their field of view is fully three degrees.

In general the cloud colors have not been unusual, although sometimes resembling the tint of "London Smoke" glasses when the customary gray is slightly tinged with green. However, in more than forty years of almost daily observing I cannot recall conditions quite like those herein described.

H. B. Rumrill.

Berwyn, Pa., September 26, 1950.

The following letter contains further comment upon certain of the phenomena mentioned above. Ed.

Perhaps the readers of Popular Astronomy would be interested in a first-hand description of the recent obscuration of the sun by smoke from the Canadian forest fire.

The smoke first arrived in late forenoon of Sunday, September 24, 1950. By mid-afternoon the sun was a deep red in color. Going to work at the Aberdeen Proving Ground on Monday, about 7:50 A.M., looking up at the sun I was astonished to see a faint disc pure violet in color. The disc had about the same brightness as the full moon before it sets in early morning. The color was unchanged when I looked again, perhaps fifteen minutes later. On Tuesday morning, September 26, a little before eight o'clock, the sun was much brighter, but it had a very astonishing lavender color. Other employees on the Proving Ground confirmed my observation, and many expressed extreme astonishment.

The reason for the unusual color assumed by the sun on these two mornings was that the dust particles of the smoke were of uniform size, and were of the right size to let only light from the violet end of the solar spectrum through. It is very rarely, I believe, that conditions are just right to produce a violet or blue sun. I have seen only one reference to it, and that was in certain supplemental volumes of an old edition of the Encyclopedia Britannica, but I cannot give page number and author because I do not have the edition available now.

Noah W. McLeod.

Apartment 2, 213 South Union Avenue, Havre-de-Grace, Maryland.

General Notes

Dr. John E. Merrill moved, at the beginning of this academic year, from Hunter College to the department of astronomy at Ohio State and Ohio Wesleyan. Dr. Merrill will give special attention to undergraduate teaching and will also share in projects related to the Perkins Observatory.

The Rittenhouse Astronomical Society, of Philadelphia, held its monthly meeting on Friday, October 13, 1950, in the Commons Room in Founders Hall, Haverford College, Haverford, Pa. The speaker was Prof. Albrecht Unsold, Director of Observatory and Inst. of Theoretical Physics of the University of Kiel. His topic was "Origin of Cosmic Rays."

Fireball of October 4, 1950

We have received a large number of communications from observers in Wisconsin and Illinois who witnessed the very bright daylight meteor which swept from northwest to southeast at $5^h\ 20^m$ P.M. on October 4. There was even some hope for a time of pin-pointing the fall when reports came in our vicinity locating the object within a few yards. Investigation on the spot showed how deceiving such appearances can be since the meteor was seen as far south as Nashville, Tennessee.

G. Van Biesbroeck.

Yerkes Observatory, Williams Bay, Wisconsin.

Provisional Sunspot Numbers for September, 1950*

1	49	11	28	21	48
2	59	12	37	22	51
3	49	13	65	23	44
4	51	14	94	24	56
5	31	15	75	25	41
6	27	16	70	26	45
7	23	17	80	27	49
8	24	18	73	28	38
9	38	19	65	29	49
10	31	20	58	30	32

Mean 49.3

From the Zürich Observatory, furnished by Mr. Neal J. Heines.

Recent Designation of Lunar Formations

During the last few years notes have appeared in various astronomical magazines, including Popular Astronomy, about newly named lunar formations. The list below includes all formations to which new names have been assigned on Mr. H. P. Wilkins' 300-inch map of the moon. Mr. Wilkins is Director of the Lunar Section of the British Astronomical Association, and his map is by far the most detailed one ever made of the lunar surface .The list was sent to me by Mr. P. A. Moore of the B.A.A. Lunar Section. The numbers following the names tell on what Section of the map the newly designated formation is located. An S means that it is on the limb on the Special Libratory Section, which Mr. Wilkins published earlier this year. This Special Section has been reproduced in *The Strolling Astronomer,* the organ of the Association of Lunar and Planetary Ob-

servers; and the complete Wilkins map is being serially published in the same periodical.

It may be noticed that there are several names of Americans in this list, including that of the late Russell W. Porter (and that of the writer. EDITOR.)

NEW NAMES ON WILKINS' 300-INCH MAP

Abineri	14	Esquivel	15 S	Mare Orientalis	20
Amundsen	23 S	Febrer	11 S	Paluzie	13 S
Arthur	16	Haas	15	Peary	15 S
Ball, L. F.	14	Hallowes	13	Porter	23
Barker	23	Ibanez	25 S	Porthouse	5
de Bergerac	5	Juan	20 S	Recorde	12
Burrell	19	Krosigk	5	Russell	13
Buss	19	La Paz	20	Scott	23 S
Caramuel	18 S	Lowe	19	Siesbut	8
Cooke, J.	12	Lower	12	Smith, C. F. O.	10
Cortes	24 S	MacDonald	18	Comas Solá	20
Darwin	20	Marth	7	Sven Hedin	19
Demonax	23	Moore	7	Thornton	16 S
Drygalski	23 S	Najera	17 S	Timoleon	12
Dyson	5	Nansen	15 S	Trewman	14
Emley	22	O'Kell	14	Väisälä	25 S
				Virgil	5

WALTER H. HAAS.

167 W. Lucero, Las Cruces, New Mexico, October 14, 1950.

The Cleveland Astronomical Society

As in former years, the Cleveland Astronomical Society, headquarters at the Warner and Swasey Observatory, is offering for this season a series of lectures on astronomy. This series is unusually attractive both in the topics to be discussed and in the astronomers who are to discuss them. Persons living near enough to avail themselves of the opportunity afforded by this series are indeed fortunate. The lectures are scheduled to begin at 8:00 P.M. in the lecture room of the Warner and Swasey Observatory and are as follows:

October 20, "Galileo the Astronomer," Dr. Georgio Abetti, Osservatorio Astrofisico, Florence, Italy.

November 10, "Interstellar Clouds," Dr. S. Chandrasekhar, Yerkes Observatory of the University of Chicago.

December 15, (Christmas Party), "An Astronomical Visit to South Africa," Dr. John Irwin, Goethe Link Observatory of Indiana University.

January 26, "Star Clusters in the Milky Way," Dr. Donald A. MacRae, Warner and Swasey Observatory of the Case Institute of Technology.

March 9, "The Magellanic Clouds," Dr. Harlow Shapley, Harvard College Observatory.

April 27, "Beacons of the Milky Way," Dr. Helen Sawyer Hogg, David Dunlap Observatory of the University of Toronto.

May 25, (Annual Dinner Meeting), "Our Place in the Universe," Dr. Jason J. Nassau, Warner and Swasey Observatory of the Case Institute of Technology.

In addition the Warner and Swasey Observatory will be open to the public on Thursday and Friday nights shown in the schedule below. The Observatory will be opened on these evenings at 7:45 P.M. and the lecture will be given at 8:00 P.M. When the sky is clear an opportunity will be given to look through the telescope after the lecture. The schedule is as follows:

October 12, 13, "Our Galaxy of Stars."
November 16, 17, "Our Sun, its Past and Future."
December 7, 8, "Life in Other Worlds."
January 18, 19, "Eclipses of the Sun and Moon."
March 15, 16, "Measuring the Universe."
April 19, 20, "The Formation of Stars and Planets."
May 17, 18, "The Summer Sky."

Contracts for Research in Astronomy and Astrophysics for the year 1951-1952

The Office of Naval Research again intends to make available limited funds for the support of pure research in astronomy and astrophysics.

The National Research Council, at the request of ONR, has appointed an Advisory Committee of eminent astronomers to recommend specific projects for support by ONR. The Committee has suggested that the average cost per project should be about $3,000, with a maximum not appreciably in excess of $5,000. It is understood that in the case where a proposal is selected for support by ONR, negotiations will be entered into for a contract between the U. S. Navy and the institution at which the research will be conducted.

The Advisory Committee has recommended that for these relatively small contracts the maximum overhead charges should not be in excess of 10 percent, but all legitimate expenses in connection with the project will be chargeable to the contract.

Applications for the support of projects to be considered this winter should be received at the Office of Naval Research *on or before December 15, 1950.* These should be addressed to Chief of Naval Research, Washington 25, D. C., Attention: Dr. Mina Rees, Director, Mathematical Sciences Division.

Each applicant is requested to submit *ten* copies of all application material (legible carbon copies on thin paper acceptable). Each application should contain a full description of the project, accompanied by a cost breakdown and, if possible, a letter of approval from the institution(s) at which the work will be performed. Letters of recommendation will be helpful to the members of the Advisory Committee in making their appraisal and should be sent by the writer directly to the above address, also by December 15.

Under the suggested arrangements it will not be possible to pay for the cost of publication of the results of the research. It is, however, understood that research results may be published freely through the usual channels.

4 October 1950.

Book Reviews

The Star Almanac for Land Surveyors, for the year 1951.—This pamphlet of 66 pages, prepared by H. M. Nautical Almanac Office, has recently been issued from H. M. Stationery Office, 429 Oxford St., London, W.1, England. From the preface we learn that the Star Almanac for Land Surveys is designed to provide precisely what the surveyor wants, in the least space and without any unwanted matter. It contains an ephemeris of the sun's position at six hour intervals throughout the year, with times of sunrise and sunset, at five day inter-

vals; also places of stars; circumpolar stars; Pole Star table; refraction tables; interpolation tables; and conversion from time to arc table. Copies may be obtained from the address given above. The price is 3 shillings.

Stellar Evolution, by Otto Struve. xiv + 266 pp. Illustrated. (Princeton University Press. Princeton. 1950. $4.00.)

Centuries ago men knew nothing about stellar evolution. That was the all-time high of human knowledge on this subject. The famous nebular hypothesis of Laplace and the plausible Lockyer-Russell theory successively took the account far below zero. The trend recently may have been upward but I doubt if we are yet out of the red. Solemn guesses on the facts of stellar life are now subject to the admonition, "When you say that, smile."

Dr. Struve's book, "Stellar Evolution," is based on his Vanuxem Lectures at Princeton in 1949. It outlines in some detail our physical knowledge of the stars, and then reviews, with no pretense of finality, current ideas concerning the formation and development of single stars and of close double stars.

The introductory discussion of the physical and chemical properties of the stars is excellent. It includes such topics as the mass-luminosity relation, the Hertzsprung-Russell diagram which relates luminosity with spectral type of surface temperature, and the cosmic abundance of the various chemical elements.

The second section of the book deals with the internal energy of stars, the formation of stars in interstellar clouds, and similar topics. It describes the recent theory of von Weizsaecker which gives special consideration to turbulence in cosmic masses and to the effect of rotation on the evolution of stars. This theory suggests a mechanism by which condensing cosmic masses may lose angular momentum and thus become stable stars rotating slowly.

The final third of the book is on the origin and developent of close double stars. For many years Struve has been a keen spectroscopic observer of the complicated phenomena of short-period binaries and of rapidly rotating individual stars. Perhaps because he is an active person he particularly admires stars with active atmospheres. In this book he emphasizes, with many interesting examples, the importance of rotating and expanding stellar atmospheres and of streams of gas set up by the interaction of the components of a binary. His superior knowledge and insight render his comments most stimulating to observers and to theoreticians seeking new phenomena to explain.

In short, this book contains much reliable and up-to-date astrophysical information about stars, particularly about close double stars, together with some high-class surmises on the probable life history of stars. The general reader will not learn much about stellar evolution but he will get an informing close-up of an alert astronomer valiantly struggling with the problem.

Paul W. Merrill.

Mt. Wilson Observatory.

Tables for Solution of Light Curves of Eclipsing Binaries, by John Ellsworth Merrill. Contributions from the Princeton University Observatory. No. 23.

The appearance of this long-awaited publication will be heartily welcomed by astronomers working in the field of eclipsing binaries. The importance of these tables is perhaps best illustrated by noting that unpublished copies have been used at various observatories during the past few years, and this use has already aided in the determination of elements of several eclipsing systems. It is to be expected

that the wider distribution now made possible will aid in the computation of many more such elements.

For convenient use, this contribution is published in five separate parts; a set of auxiliary tables is to be added soon. Each section tabulates the familiar χ, ψ, ϕ, and α functions for a fixed degree of limb darkening; all sections except the first include the n^{ann} and k functions. Degrees of darkening represented are $x = 0.0, 0.2, 0.4, 0.6$, and 0.8. Included also are notes on interpolation and formulae for computing the α functions for non-tabular values of x.

The system of notation used is clearly described in the introduction. This is a notable attempt to eliminate some of the confusion which has arisen in the past. The system presented is the outcome of many discussions between Professor Merrill, Professor H. N. Russell, and the late Professor Newton L. Pierce; the adherence to it by astronomers working in the field is strongly recommended.

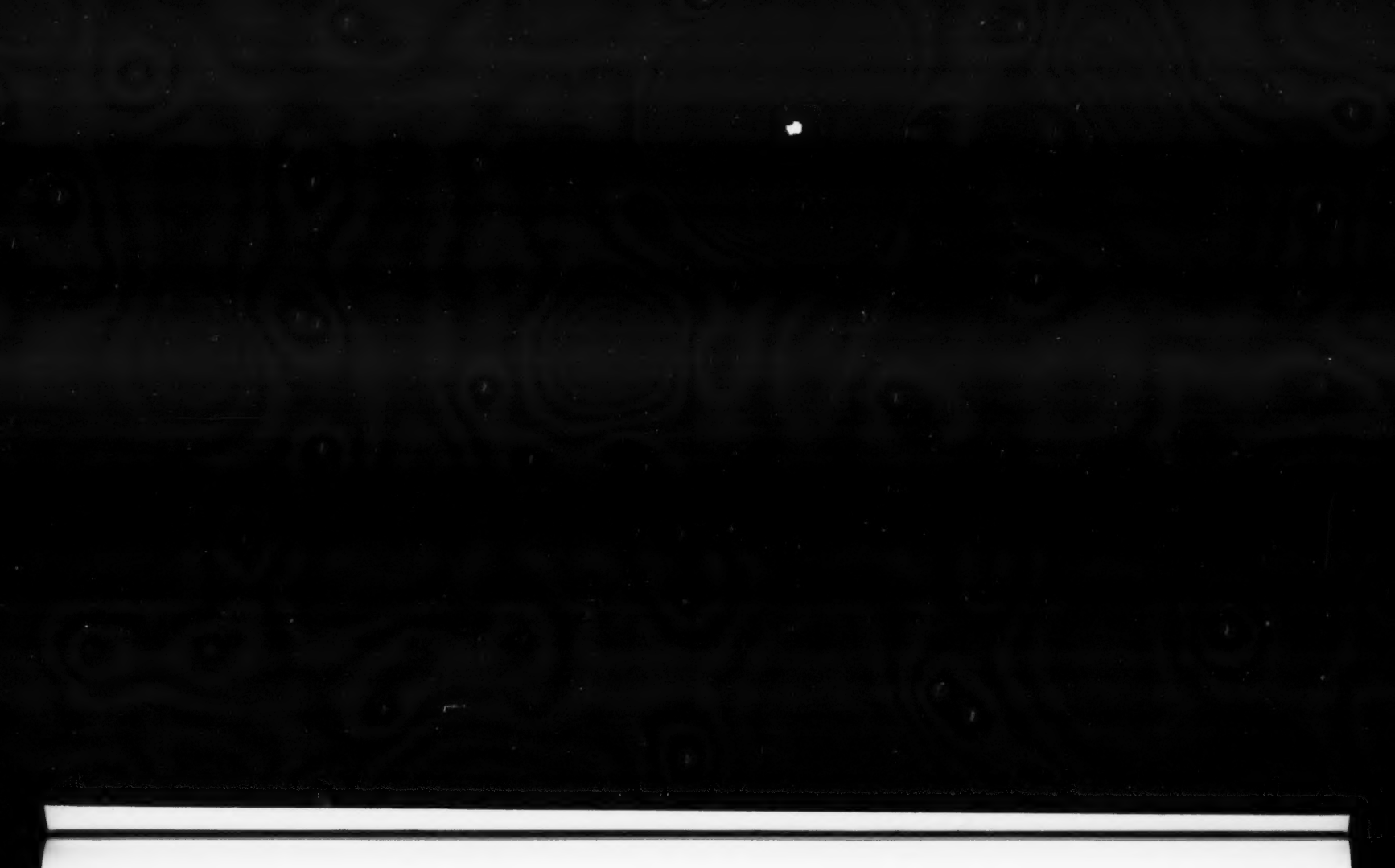
The introduction contains more than the system of notation and the generating definitions of the tabulated functions. After brief historical remarks, the author discusses two idealized models of eclipsing systems which he designates as the "Russell Model" and the "Kopal Model." The present tables deal with the solution of light curves on the basis of the "Russell Model." This model can be converted into the simple "Spherical Model" by the familiar process of rectification, or removal from the light curve of such effects as ellipticity and reradiation. The twofold advantages of the "Russell Model" are discussed. "On the one hand it yields computed light curves approximating the observed ones amply well in the great majority of cases so far studied. . . On the other hand the transfer from the Russell Model to the Spherical or *vice versa* is effected by simple expressions in the elementary trigonometric functions." The "Kopal Model" is an attempt to approximate somewhat more closely actualy systems by considering various higher order terms. The author points out that the best method of investigating a given system is to find the best "Russell Model" fit and then to proceed from this to the further laborious computation if such seems desirable. In general, this will be advisable only if the observations are of the highest precision, the light curve of the type which yields a sharply determinate solution, and the system free of such phenomena as streaming, patchiness, and intrinsic variation. The remainder of the introduction gives some details of methods of computing and checking the various tables and offers a few practical suggestions as to their use. No extended discussion of methods of solution is undertaken.

It is highly encouraging to read that this is only the first of a series of Contributions. It is to be followed by a contribution on the geometrical-physical background, a set of nomographs for aid in preliminary solutions, a Contribution devoted to detailed explanation of solutions of light curves, and possibly a derivation and analysis of the basic functions. It is hoped that nothing will unduly delay publication of the remainder of this series. Such a collection would form by far the most important aid to interpretation of light curves of eclipsing systems since the pioneer papers of 1912-13.

FRANK BRADSHAW WOOD.
Flower and Cook Observatories, University of Pennsylvania.

Worlds in the Sky, by Carroll Lane Fenton and Mildred Adams Fenton. (The John Day Company, Inc., 62 West 45th Street, New York, N. Y. 96 pp. $2.50.)

This is a recent book setting forth the elementary aspects of astronomy. The authors have adopted the device of using a large part of many of the pages for

pictorial representation. Thus the reader is instructed by illustration and text simultaneously. One's first impression in looking at this book is that it is intended primarily for children. It is, indeed, written so simply that children can comprehend it. But it is also suitable for grown up people who may never have given any attention to the night sky. Such persons are really like children in that they are entering a hitherto unexplored field of fact.

The book is divided into nineteen chapters ranging in titles from What the Earth is Like through The Sun's Big Family and Eclipses of Sun and Moon to Star-Pinwheels or Galaxies. Naturally in the small compass of 96 pages, details and great rigor of presentation must be omitted. However, the salient, interesting, sometimes spectacular, and well-established facts are included. A reading of this small volume and a study of the pictures in it will give anyone an introduction to the universe in which he is living, and he will find it an exhilarating experience. —C.H.G.